A Case Study: Number Apps In Preschool

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A CASE STUDY: NUMBER APPS IN PRESCHOOL

By

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Abstract

iPads are increasingly present in education. This research explores their role developing fundamental mathematics concepts. It investigates preschoolers’ interactions with mathematics apps, and affordances and constraints accessed. It was conducted over fourteen weeks; students played mathematics apps for thirty minutes a week. The qualitative case study design included participants who varied in mathematics and technological skill. Data was collected through assessments, interviews, questionnaires, videotapes, and artifacts. Results determined that students access constraints or affordances based on ability level. Findings indicate iPads are beneficial tools for preschool classrooms. Preschoolers showed an increase in math ability when using iPads.

*Keywords*: number sense, iPad, affordances, constraints, preschool
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Chapter 1: Introduction

Background and Context

Chapter one of this dissertation provides background information for this research and consists of a review of research on number sense, essential definitions, and a discussion of the potential for technology to aid children’s understanding. Chapter two investigates more thoroughly and deeply the Constructivist framework for this study and how children learn through constructivism, then connects these theories to research on children learning through technology. Additionally, chapter two has a section about affordances and constraints. Chapter three includes a justification for and design of a qualitative case study to describe students’ interactions with number sense iPad apps, and what affordances and constraints of those apps were most often accessed (as observed). Chapter four provides data analysis and results. Chapter five gives the conclusion, discussion, and future implications. Three main areas of education are connected: that of early childhood mathematics development of number sense, curriculum, and pedagogies for young children, and technology implementation of the iPad with young learners. The examination of early childhood mathematics classrooms is a recent emerging interest for several reasons (Clements & Sarama 2007). The iPad is the latest technological tool to be implemented into the mathematics classroom (Spencer, 2013). Technologies have been depicted as being potentially transformative in the learning process (Fullan, 2012). However, very modest amounts or no empirically-based guidelines on how to implement technologies in the classroom have been established (Means, 2010). In fact, there have been few attempts to analyze specific programs in mathematics education, even though digital content is more and more present in the United States’ K-12 classrooms (Choppin, Carson, Borys, Cerosalwtt, & Gillis, 2014).
Mastery of foundational concepts, such as number and quantity, at a young age has been found to promote successful skills in later mathematics (Clements & Sarama, 2007). Elementary-aged scholastic advancement is important to future academic success (Entwisle and Alexander, 1998). Technology is an educational resource to supplement classroom instruction and can support students in school learning processes (Taylor & Parsons, 2011); iPads can function as a medium for preschoolers to understand mathematics (Sherr, 2011). *Principles and Standards for School Mathematics*, produced by The National Council of Teachers of Mathematics (NCTM), considers technology a major principle that describes characteristics of a high-quality mathematics education. NCTM describes technology as being paramount to the teaching and learning of mathematics. Technology improves students’ understanding, as well as influences mathematical content and teaching delivery. NCTM suggests that technology be used wisely by knowledgeable teachers who support effective mathematical understanding (National Council of Teacher of Mathematics, 2000).

The National Mathematics Advisory Panel reported that mathematics is more and more significant in the current modern global economy, which causes more focus to be placed on mathematics learning (Clements & Sarama, 2014). Moreover, there is an increased awareness of the significance of mathematics (Kilpatrick, Swafford, & Findell, 2001). Important to the 21st-century learner is the ability to think critically and be able to utilize technology to solve problems (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur & Sendurur, 2012). Innovative skills, which include analysis, problem-solving, collaboration, and creativity, are important for the next generation of learners (Levin & Schrum, 2012); moreover, each of these skills are exercised in the mathematics-based number sense apps this study investigates. The importance of technology
and mathematics automatically highlights the significance of examining quality experiences in
the pre-k classroom with iPad number concept apps.

Why Is the Mathematics Discipline Important for Young Learners?

Consistently, American students are eclipsed in mathematics competencies when
compared to students in other countries, even as early as preschool, kindergarten, and first grade
(Mullis, Martin, Foy, & Arora, 2012; Sarama & Clements 2009). In addition to being
outperformed internationally, further gaps in academic achievement are found within the United
States when looking at children from different economic backgrounds, genders, and races
(Thames & Ball, 2013). Gaps in both income and achievement have been increasing between
children raised in high and low resource communities for decades (Reardon, 2011). These
alarming facts highlight the need for focused research on early childhood mathematics concepts,
particularly in low-income communities. This research seeks to address these gaps.

There has also been a shift in the way researchers view the development of mathematical
ideas in the early childhood years. It was once thought that young children had little
understanding of mathematical concepts. However, recent views indicate pre-existing knowledge
of mathematics at a very early age. Prior knowledge of numerical ideas can be a strong indicator
of mathematics achievement (Krajewski & Schneider, 2009). Most young children learn
substantial knowledge of numbers and other mathematics concepts before entering kindergarten.
This is vital, because the prior knowledge of mathematics that kindergarteners bring to school is
connected to their mathematics understanding for years to come. Unfortunately, most children
from low-income backgrounds have less knowledge of mathematics when they enter school and
the achievement gap in mathematics continues to grow throughout their pre-kindergarten through
high school years (National Mathematics Panel, 2008).
There is a slight increase in the amount of children enrolled in pre-kindergarten programs (Clements & Sarama, 2007). Children from low-income families perform lower in mathematics competencies than children from middle class or higher income levels. The disproportional representation of minority children in low-income families results in racial and social-class inequalities in mathematics classrooms. These pre-kindergarten classrooms are interconnected with reduced and weakened mathematics learning opportunities (Jordan & Levine, 2009).

Pre-schoolers are experiencing classrooms that include small amounts of mathematics curriculum where weak content connections are taught (Clements, 2001). Mathematics instruction is secondary to other learning goals (Stipek, Schoenfeld, & Gomby, 2012). Although there has been improved remediation as part of school mathematics instruction reform for grades K-12, there is still a need for supplementary mathematics instruction, especially to enrich mathematics for early learners (Mathematics Learning Study Committee, 2001). The academic achievement gap is most prevalent in low-economic urban neighborhoods. Unfortunately, the schools in these areas generally have overcrowding issues and a lack of funding that create a shortage of educational materials (Siegler, 1993).

Children in preschool have a natural comprehension of a wide-range of high-level mathematics skills. In the years before formal schooling, free play is important for young children. Young children investigate by counting objects, recognizing spatial relations, and exploring shapes and patterns (Seo and Ginsburg, 2004). Children of all income levels and genders appear to engage in critical mathematical reasoning in countless contexts if they are familiar and comfortable. There is research that indicates that foundational mathematical knowledge begins early in a child’s life. It appears that numbers come just as natural as language. The National Center for Education Statistics reported in 2000 that “94% of entering
U.S. kindergartners could count to 10 and recognize numerals and shapes, and 58% could also read numerals, count beyond 10, make patterns, and use nonstandard units of length to compare objects” (as cited in Clements & Sarama, 2007, p. 463) According to Clements, Sarama, and Gerber (2005) about 68% of a sample of low-income pre-school children could count to 5, and approximately 44% could count to 10. Less than 50% of students could count objects in small groups (as cited in Clements & Sarama, 2007).

Students who acquire concrete foundational mathematics skills at the elementary level have success in higher-levels of mathematics in the future (Carr, 2012). A variety of factors can affect the learning of mathematics, such as early childhood experiences, cultural attitudes, language structure, and learning capabilities (Jordan, Glutting, & Ramineni, 2010). Important to our increasingly technological society, all children need to have strong mathematics achievement (Jordan & Levine, 2009). Mathematics knowledge significantly influences careers that rely on science, technology, and engineering (Jordan et al., 2010). Underdeveloped skills in mathematics lead to substantial negative impacts on daily living and advancement in careers (Jordan & Levine, 2009). Non-mastery of mathematics can lead to alternate careers path which usually result in less economic gain. The need to address the educational decline in schools is necessary for a revitalization of the United States’ economic status and its capability to become a substantial global competitor once again (US Department of Education, 2010).

Why the iPad?

**Increasing technology in the classroom.** As technologies are becoming increasingly intertwined in our daily lives, schools are attempting to implement technology to provide excellent learning experiences for children (Agostini, Biase & Loregian, 2010). Technology in K-12 mathematics classrooms manifests in a variety of formats. Smart-boards, interactive
mathematics programs, and computers are among the most commonly used tools (Pierce & Ball, 2009). Virtual manipulatives on the computer have been shown to be extremely beneficial for gaining academic knowledge (Clements & McMillen, 1996). The latest mobile technology to be added to the list of educational tools for the mathematics classroom is the iPad, which maintains new and innovative methods of accessing and linking information for learners (Henderson & Yeow, 2012).

Technology in the mathematics classroom can engage students by breaking abstract concepts into visual representations, making mathematical connections more achievable for learners: “[t]he power and versatility of a wide array of sophisticated electronic tools available for teaching and doing mathematics have transformed the way that we can engage students exploring mathematical ideals and solving mathematical problems,” (Hollenbeck et al., 2010, p. 265). Instruction with technology that displays physical representations can enhance the understanding of mathematics (Habre & Grundmeier, 2007).

Ultimately, technological integration into the classroom will only increase. Technological advances, however, often occur too rapidly for academic research to keep up. Thus, a qualitative approach is appropriate to this study’s goals: more intimately understanding what happens when children learn via technology.

Mobile learning in the classroom. For many years, mobile learning in education has evolved in classrooms (Johnson, Levine, & Smith, 2009). Further, it fosters opportunities for anytime learning for impoverished children. Mobile learning helps build skills needed for 21st-century communication and collaboration. Additionally, it allows for personalized learning that can be targeted for the specific needs of a learner (Shuler, 2009). Young children’s routine use of interactive touch screen devices such as iPads and smartphones are rapidly growing (Radesky,
Schumacher, & Zuckerman, 2015; Cristia, & Seidl, 2015). Digital devices are quickly becoming ubiquitous in the lives of early childhood classroom and homes (Verenikina & Kervin, 2011). The iPad and tablets offer children anytime, anywhere learning (Radesky, Schumacher, & Zuckerman, 2015; Brand & Kinash, 2010) due to the devices’ portability and ease of use. There is very little research about young children and learning with iPad apps, but there are a variety of reasons to explore this topic, such as the personalization of learning, play-based learning, immediate feedback, and motivation (Spencer, 2013).

**iPad applications.** The iPad, a mobile electronic tablet, can use application inquiry-based lessons that support a shift in the teaching of mathematics by focusing on more student-centered activities that are different from the traditional mathematics teaching strategies (Preciado-Babb, 2012). Practice apps, skill-based apps, simulation apps, and interactive apps can provide opportunities to improve foundational mathematics skills.

iPad applications provide opportunities for students to engage through more problem-solving and collaborative methods, often promoting student-centered approaches (Preciado-Babb, 2012). Interactive programs accessed through the iPad allow for new ways to explore the discipline of mathematics. Among some of the tools available are GPS devices, webcams, online polling sites, recording devices, spreadsheets, cameras, and applications set up in a game-like or puzzle-based framework (Attard & Northcote, 2012). These types of applications can enhance the engagement of the learning and teaching of mathematics (Preciado-Babb, 2012). Free integrative games or puzzle-like applications can be downloaded for any age group to promote students’ engagement. Some of these apps can focus on drill and practice through a game-like environment. Some applications specialize in targeting specific skills or objectives (Attard &
iPads not only provide applications with rich mathematical investigations, but also support student-student and student-teacher communication and collaborative efforts.

The iPad offers a robust explosion of educational apps for young learners. Despite the richness of available app content, very few of these “educational” apps have been evaluated or tested. What students learn depends significantly on how information is presented and explained. Electronic information technologies used as instructional tools offer unique opportunities for transforming the mathematics learning environment (Hollenbeck, Wray, & Fey, 2010).

**Disadvantages of the iPad.** A disadvantage of iPads is that they have entered the mathematics classroom with little research to support their overall effect on the teaching and learning process (Technology in Education, 2016). Furthermore, teachers are often asked to implement new technologies with limited training and a lack of professional development (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur & Sendurur, 2012). Students can also feel frustration if they lack skills to operate the iPad correctly, which can lead to the technology becoming the focus of the lesson, instead of the math. This disadvantage, however, can change when students and teachers become more adept with the technology (Preciado-Babb, 2012).

**Need for best practices.** Some research reports little evidence that academic achievement is affected by iPad implementation (Van Oostveen, Muirhead & Goodman, 2011). Romney (2009) found an increase in mathematics-related memory and ability when students used iPads to listen to audio recordings of instruction lessons (as cited in Manuguerra & Petocz, 2011). Further research is needed to completely understand how iPads change the learning environment in the mathematics classroom. A clear vision of how the iPad should be used has not yet been set, but one-to-one interaction is reported to engage the student (Bennett, 2011). Other teachers and researchers report that using the iPad in a small group setting can be
beneficial in promoting collaborative activities. The verdict is still out on whether the iPad is best suited for one-to-one use or sharing among paired students (Quillen, 2011). Lots of variables affect the use of the iPad in the classroom. School infrastructures may not have enough technology leaders, learning resources, or professional development opportunities.

**iPads, constructivism, and the mathematics classroom.** Additionally, iPads allow access to educational information, programs, and apps to support the learning process (Hutchison, Beschorner, & Schmidt-Crawford, 2012). The iPad features content-specific apps that provide new forums for the intersection between learning and playing for preschool children. Apps afford interactions with content that is both fun and engaging for learners, while offering educational elements of immediate feedback, appropriate learning levels, and topics targeted to the ability levels of students. The iPad offers flexibility and portability in where learning can take place and access to countless educational programs. It can support communication and collaboration within the educational environment on different levels such as teacher to teacher, student to teacher, and student to student (Pilgrim & Bledsoe, 2012). These elements reflect a deeper connection to a Constructivist view of learning than ever before with respect to technologies (Manuguerra & Petocz, 2011). A current literature review reported the easy-to-use iPads supports learning in a variety of positive ways such as bringing inspiration, engagement, eagerness to learn, self-guided and self-regulation of learning, creative components, and increased productivity (Clarke & Luckin, 2013). Other research has investigated children’s technology use in the home and found that it promotes communication, creativity, and student abilities (McPake, Plowman & Stephen, 2013).

**Multimodality and the role of touch in children’s learning.** The iPad provides children with an unmediated form of engagement via touch. Younger learners may find this mode of
interaction more intuitive than mediated technologies, such as traditional computer-mouse-keyboard navigations. This direct touch technique encourages young children’s learning in a way that mirrors their natural inclination to explore their multisensory world (Lucrezia Crescenzi, Carey Jewitt, and Sara Price, 2014). Integral to early knowledge acquisition and childhood development, touch is a central medium for children’s learning. When presented in conjunction with other sensory systems (sight, sound, etc.), multimodal learning via touch can bolster children’s understanding (Smith & Gasser, 2005). Furthermore, the iPad promotes multimodal learning, which has been found significant to reconfiguration and the interplay between representation (in this case, numerical representation) and interactions. The multimodal elements of the iPad could help define and categorize affordances and constraints observed during this research; where multisensory elements include hearing, seeing, and touch, the iPad apps’ multimodality is instead invested in modes: vision, sound, and gesture (Crescenzi, Jewitt, and Price, 2014).

Research Questions

1. How do 4- to 5-year-old preschoolers interact with mathematics-based number sense iPad apps for learning?

2. What affordances and constraints are accessed by 4- to 5-year-old preschoolers when interacting with number sense iPad apps, as observed via video recording?

Rationale of the Study

The integration of technology into classroom settings has often occurred without any research-driven guidelines (Means, 2010). This research provided insight on the observable behaviors of young learners working with iPads in a preschool mathematics setting. It evaluated what happened on the iPad and what affordances helped enhance academic gain for children in
number sense understanding. This research is crucial for adding to the existing body of knowledge due to the newness of the iPad’s implementation into the mathematics classroom.

A disadvantage of iPads revealed by empirical studies is that they have entered the mathematics classroom with little research to support their overall effect on the teaching and learning process (Editorial Projects in Education Research Center, 2011). There are various gaps in the research, such as how effective the implementation of the iPad is in the mathematics classroom, what types of students are best suited to learn on the iPad, what types of applications promote successful learning, and the best practices for the learning and teaching of mathematics with iPads.

Further research is needed to completely understand how iPads change the learning environment in the mathematics classroom. It is also currently apparent that, to teach students in this next generation, teachers must acquire new teaching strategies to shape inviting educational experiences (Manuguerra, & Petocz, 2011). Mobile devices like the iPad have several affordances and constraints for learning in education. The portability of the iPad can transform learning and collaborative activities (Laurillard, 2007). Mobile devices allow for individualized and customized options that allow for scaffolding and personalized learning (Peters, 2009).

Theoretical Introduction

Constructivism is a theory of learning and method of education that stresses the importance of how people construct meaning in the world around them; it is embedded with theories developed by Dewey, Piaget, and Vygotsky. The continuous interaction between building on prior knowledge and reflecting on one's environment promotes meaning, allowing the learner to gain knowledge even through mistakes or errors (Heddens, Speer & Brahier, 2009). Constructivist principles would first activate prior knowledge of the mathematical
concept, then explore instruction using action in the form of hands-on activities with context in the real world, and, finally, create opportunities that develop clear, meaningful constructions of mathematics in a social setting, working with peers, teachers or interactive technologies. Mathematical concepts are at times abstract and often the process of understanding requires struggling through challenging problems. Reflection and transferring key concepts to new situations are among the goals in a constructivist-based instruction approach (Moffett, 2010).

The following is a summary of characteristics for the teaching and learning of constructivism. When presenting answers to a question, multiple solutions, perspectives, and representations are encouraged. Teachers’ roles are to help guide students in mastering knowledge by facilitating, coaching, and tutoring. Lessons are more student-focused and allow students to play a central role in the learning process. A variety of activities, teaching resources, and opportunities are supplied to inspire thought, self-examination, self-discipline, self-reflection, and self-awareness. The curriculum covered, skills learned, and tasks performed in a constructivist learning environment should be authentic, appropriate, and realistic. Each learning situation should represent natural complexities encountered in the real world. In constructivist classrooms, emphasis is placed on the construction of knowledge, not the simple reproduction of knowledge. Learning opportunities in these classrooms are supported with conversation, collaboration, and experiences. Students’ existing abilities, perspectives and opinions are preserved as part of the learning process. Critical thinking, problem-solving, and high-cognitive demand tasks are highlighted to allow students to gain a deeper understanding of concepts. Exploration methods are encouraged so students can independently seek knowledge. Subjects’ complexity should be addressed from a conceptual interrelatedness and interdisciplinary approach. Collaboration with peers should be included to expose students to others’ viewpoints.
Scaffolding should be implemented to help children perform just past their current ability. Assessment should be realistic, authentic, and intertwined with the teaching (Murphy, 1997; Jonassen 1991, 1994; Wilson & Cole, 1991; Ernest, 1995, Vygotsky, 1978). All of these characteristics are evident in the mathematics-based iPad apps selected for this study. These ideas must be connected to this research and the apps’ features that offer constructivist models for learning.

Currently there is a considerable amount of research that supports constructivist approaches. It is a theory that can influence curriculum, instruction, and assessment in all subjects. It is especially relevant in mathematics education because mathematics is a discipline that requires a cumulative understanding in which students build new knowledge on previously learned knowledge (Moursund, 2015). In short, here are some main views about constructivist principles in mathematics education. Humans are born with the ability to deal with small numbers such as 1,2,3,4 and to make comparisons and estimations. People at a very early age can learn and use math. However, individuals can vary in their innate mathematical intelligence. Additionally, mathematical learning can be affected by the mathematical opportunities that are given to children. These opportunities can vary tremendously. Due to this, by the time children start kindergarten, there are a wide array of levels of mathematical understanding, skills, and interest. Often, mathematics curriculum itself has varying instruction, assessment, and engagement. At any grade level in any mathematics course, there are huge differences in the mathematical knowledge of the students within the classes. Therefore, mathematics curriculum, instruction, and assessment have to keep in mind the needs of all students at different levels. One way to do this is through constructivist teaching and learning approaches (Moursund, 2015).
Definitions

**iPad.** iPads are not quite smartphones, netbooks or tablet PCs, but they have some components of all three (Henderson & Yeow, 2012). The iPads’ simple, modernized style allows for flexibility and mobility in learning for users, but with the capabilities of a computer (Melhuish & Fallon 2010). iPads allow for anytime access to hundreds of educational apps for download and purchase. This mobile device additionally allows for wireless connectivity to the internet, which is host to a vast amount of content. iPads do not need devices, such as a keyboard or mouse, for operation. Navigation on iPads, for example when moving between apps or internet sites, is done through finger touches alongside screen rotation according to users’ preferences. This grants the learner a more personalized and interactive experience through a multi-touch screen (Henderson and Yeow, 2012). Handheld devices, with their wireless interconnectivity, present a learning space that favors constructivism and collaboration that permits the construction of new knowledge (Zurita & Nussbaum, 2004).

**Number sense.** Judith Sowder describes nine skills needed to learn number sense. These characteristics include the abilities to: compose and decompose numbers, identify the relationship between numerical quantities, and utilize benchmarks. Additionally, a child needs to be able to link representations, operations, and number symbols. Also, children need to have knowledge of arithmetic operations, perform mental computation, create strategies for estimating, and acquire an intuitive sense of numbers (Sowder, 1992). Number sense involves a holistic, intuitive understanding of numbers and their relationships; it is developed through multifaceted encounters with quantities and numerals, both in the formal classroom setting and the real world (Hilde Howden, 1989). Children’s ability to perform these operations begins with
the early stages of quantitative reasoning that can start by age two. The basic intuitive skills that children have from birth help to create a foundation for learning.

**Number sense apps.** Applications for this study were specialized programs downloaded from app store that provided digital curriculum of number concepts through interactive virtual manipulatives, games, and puzzles. Math Shelf is one of the number sense apps used in this study. It is a digital preschool curriculum that provides Montessori physical manipulatives in a digital environment. The manipulatives included beads, dot cards, number rods, golden beads, and a hundred counting board (Schacter & Jo, 2016). The other apps used in this study are TouchCount, Elmo Loves 123, and Count, Sort, and Match.

**Affordances.** Burlamaqui and Dong (2014) define affordances as “‘cues of the potential uses of an artifact by an agent in a given environment’” (p. 13). The term “affordances” refers to opportunities the app provides for learning. Much like Moyer-Packenham et al. (2016), the terms “access” and “access an affordance” are used “to describe an observable action by the child with the affordance, whereby the child attends to the cues of the potential uses of the virtual manipulatives in a way that is observable” (p. 82). This research observed via video to analyze the role that the most beneficial and frequently-accessed affordances play in observable changes in children’s learning performance and efficiency. It additionally analyzed via interviews preschoolers’ interactions with digital manipulatives in iPad mathematics apps. A more rigorous definition and explanation of affordances and their role in this research is available in chapter two.

**Constraints.** Constraints provide structure and direction for an action prompted by an affordance. They restrict the possibilities for interaction.
**One-to-one setting.** A one-to-one setting in this study refers to a learning setting where one child uses one iPad. In this setting, one child played independently on the different iPad number sense apps.

**Test of Early Mathematics Ability (TEMA).** Generally speaking, this test measures number sense in young children. Specific examples for the age group of interest can be found in Appendix A (Ginsburg & Baroody, 1990).

**Virtual manipulatives.** A virtual manipulative is defined by Moyer et al. (2002) as a digital representation of a real-world object that stimulates the acquisition of mathematics knowledge. The dynamic objects in this study are the moveable objects used in most of the iPad apps’ performance tasks, which include rods, counters, and beads.

**Novice.** For the purposes of this study, a “novice” is a student who is unfamiliar or unaccustomed to navigation or interaction with iPads and/or iPad apps. This information was gathered via the parent questionnaire prior to participant selection.

**Experienced.** For the purposes of this study, an “experienced” student is one who is familiar or accustomed to navigation or interaction with iPads and/or iPad apps. This information was gathered via the parent questionnaire prior to participant selection.

**Multimodality.** For the purposes of this study, the “multimodality” of the iPad involved its modes of operation: vision, sound, and gesture (Crescenzi, Jewitt, and Price, 2014).

**Interactions.** When using the term “interaction,” this research study is interested in actions that pertain to number concepts that can be observed and measured throughout the study’s duration. Specifically, as described on the observation protocol (Appendix B), the researcher defines the “interactions” of interest to this study as: successful navigation of app content, identifying, ordering, and matching numbers 1-10, responses to app prompts, matching
numerals to visual representations of quantity, ordering smallest to largest quantities, and any other data that can be gleaned from recorded touch counts.

**Scaffolding.** Scaffolding can be understood as a method or form of instruction that encourages students to achieve comprehension. It uses hints and other types of feedback to adjust the student’s performance and direct them towards the correct response and, ultimately, comprehension (Laffey, Espinosa, Moore, & Lodree, 2003).
Chapter 2: Review of Literature

Number Sense Framework

Introduction to the early development of quantity. It was once believed that young children were not equipped to learn number concepts until about around the age of 6 or 7 (Thorndike, 1922). However, research from the last two decades have confirmed the contrary to that belief preschoolers show development of mathematical intelligence before formal schooling. The most significant findings from this research surround children’s understanding of numbers (Clements & Sarama, 2007). The nativists claim that, in the first six months of life, babies are able to identify one object from two and two objects from three (Berk, 2003). The result of this claim led some researchers to conclude that infants use subitizing. Recently, the results of number experiments have led researchers to question if infants are responding to changes in contour length, area, mass, or density. There are two types of evidence that suggest infants respond to numbers. Firstly, infants responded to temporal sequences as well as objects. Secondly, infants showed cross-modal number abilities. In recent years, these findings have been challenged and disputed. Overall, research results claim that children are able to discriminate objects based on quantitative skills and that these skills form a foundation upon which children build numbers and quantitative skills (Clements & Sarama, 2007).

**Number sense and quantitative thinking.** Numbers and operations on numbers are usually the primary focus of mathematics for young children and the most important themes concerning the learning of math. Number and operations is a well-developed area of mathematical research, (Baroody, 2004; Kilpatrick, Swafford, & Findell, 2001) that is supported by numerous psychological and early childhood studies (Clements & Sarama, 2007). Counting is a fundamental skill in the development of mathematical knowledge. Counting is a complex
process that involves thinking, perception, and often movement of manipulatives (Kilpatrick, et al., 2001). Counting starts with preverbal number knowledge in infancy. Next, the child gains symbolic number knowledge and subitizing skills (Jordan & Levine, 2009). In counting, children must understand the objects to be counted. Also, in the counting process, children need to use manipulatives such as blocks, beans, marbles, or candies to form a concrete understanding of quantity. Next, the child assigns a number name to the objects being counted. The final step is for the child to connect the verbal representation (the name of the number) to the objects in a set (Kilpatrick, et al., 2001). Most children in preschool and kindergarten learn to count objects in order by 1, 2, and 3, then understand the final number pronounced corresponds to the total number of objects (Jordan & Levine, 2009). Counting is more than reciting number words in order: children must also be able to associate the number words with objects to be counted.

*Subitizing.* Elements most important to early numeracy development are subitizing, verbal and object counting, comparing, ordering, recognizing representations, identifying numerical numbers, and estimating (Clements & Sarama, 2014). Subitizing is when a child can look at a group and recognize without counting the number of objects in the set. Subitizing is considered a rudimentary mathematical skill. It is seen as a foundational counting strategy because subitizing involves both the understanding of whole and unit items. For example, in the recognition of the number 2, a child should understand that the set contains two elements (Clements, 1999). Also, in the counting of number 4, a child should understand that there are 2 groups of 2.

Some of the models that detail subitizing were created around the belief that subitizing is a more basic skill than counting. Based on research finding, researchers conclude that subitizing is used by infants and small children before counting skills are acquired. However, there are few research findings that dispute the suggestion that subitizing is used before counting. These
counterclaims suggest that subitizing is formed later than counting and is employed as a short cut to counting (Clements & Sarama, 2007).

There are several different types of subitizing categories. Perceptual subitizing is when a child determines the exact number of objects in a set by just looking at the set. It is the ability to “recognize number without consciously using other mental or mathematical processes and then naming it” (Clements & Sarama, 2007, p. 472). Perceptual subitizing is a quick and immediate response. For example, a child might see two dots on a die and recognize the total number of objects in the small set intuitively without much thought. Conceptual subitizing is when students see the part and put the parts together to see the whole. For example, a child might see eight on a die and recognize that eight is composed of two sets of fours (Clements & Sarama, 2014). Also important to subitizing is the patterns created for visual representation of the numbers. Spatial patterns like those seen on dominoes is one example, but there are also finger patterns and rhythmic patterns (Clements & Sarama, 2007). Researchers have found that spontaneous subitizing is an important mathematical process. This skill is linked to the formation of cardinality understanding, counting skills, and arithmetic skills. In the final stages of subitizing, the child forms conceptual patterns that they are able to build upon and thus gain mathematical growth.

**Verbal and object counting.** Number words are important and can lead children to understand numerical meaning. Without using language, it is nearly impossible to have a number system. Verbal language systems articulate the naming of numbers and operations of numbers. Studies suggest that there are differences in the learning of counting in different languages. East Asian languages such as Chinese have a better sequence of number words than English does. The number words in Asian cultures can be pronounced easier. Results show that children who speak
Asian languages are advanced in verbal counting. In languages that are not so mathematically aligned, children show inabilities in place value, multi-digit arithmetic, and other concepts. There are two phases of verbal counting. The first phase is the acquisition phase. The second phase is the elaboration phase. The acquisition phase is divided into three parts of a sequence. The first is the stable conventional, the second is the stable non-conventional, and third is the non-stable group. The elaboration phase is divided into five different levels. These are: string level, unbreakable list level, breakable chain level, numerical chain level and bidirectional chain level (Clements & Sarama, 2007).

When learning to count objects, children combine their knowledge of number words with an action, such as pointing. When children are first learning to count objects, it is easier for them to count small objects in a line so that they are able to touch the objects as they count. With practice, children are able to count larger collections in various patterns. The progression of object counting is a very important tool for children to grasp: “The capstone of early numerical knowledge, and the necessary building block for all further work with numbers and operations, is connecting the counting of objects in a collection to the number of objects in that collection” (Clements & Sarama, 2007, p. 476). Researchers speculate that children have a natural ability for counting that is based on an intuitive knowledge of counting principles. The nativists believe that children’s understanding of the principles leads them to gain counting skills and numerical understanding. Other researchers believe that, through repetitive counting practice, children develop the knowledge of counting principles. After multiple studies, it has been discovered that young children do not have an understanding of the principles. However, the evidence is not strong enough to disprove the nativists’ claim. The claim is neither supported nor disproved (Clements & Sarama, 2007).
When young children are learning to count, they do not have the concept of zero. Researchers believe this may be due to children’s need to touch objects as they count. Kindergarten children often show the understanding of zero representing absence, but the evidence shows that they are learning this fact separate from counting. Children’s knowledge of infinity varies. Some young children are not able to grasp numbers above one hundred; other children understand that it is always possible to attain a bigger number (Clements & Sarama, 2014).

**Ordering and ordinal numbers.** The ordering dynamics of numbers establishes the *more* and *less* placements of numbers. Numeral ordinality distinguishes five as being greater than two. The understanding of ordinality, coupled with cardinality, provides the conceptual understanding of numbers. Cardinality is “the ability to represent the number of discrete entities in a set and to appreciate the numerical equivalence of all sets whose members can be placed into exact one-to-one correspondence” (Brannon & Van de Walle, 2001, p. 54). Once children have obtained this level of knowledge, the ability is utilized in various situations throughout their lifetimes. Verbally, the ordinal aspect of number represents the placement of a numeral in the counting arrangement.

**Comparing.** Comparing and creating equivalence relations typically begins in infancy. An example of an equivalence relation in infants is when an adult will trade a baby a different toy for the object a baby possesses. If the baby trades, an equivalence relation between the object and the toy is created. Research shows that children seem to use the number of objects in comparison and show signs of representing cardinality non-verbally. It has also been shown that by age three, children are able to determine if groups consisting of only a few objects are equivalent. By age 4.5, children are able to determine if random sets of objects or dots are equivalent. Researchers
have discovered that children’s difficulty in establishing equivalence relations is usually accompanied by skill deficiency in number comparison. Studies have shown that this deficiency may be caused by young children’s mistrust of counting and their inability to recognize situations as counting appropriate tasks. During pre-school years, children further develop counting skills and are able to compare the equivalence of two collections of objects. Counting is a significant part of a child’s ability to determine equivalence relations. Counting skills develop progressively and by age five, children are able to count and make correct decisions about equivalence based on counting. Counting is a main focus of children’s learning through pre-school and kindergarten. The focus is to enhance children’s understanding of number. Infants perhaps rely on approximate analog magnitude. Analog magnitude allows the child to capture an approximate representation of numbers. Griffin (2007) notes that four-year-old children can differentiate between quantities. Specifically, young children can discern which pile of objects is greater or less (Jordan & Levine, 2009).

Constructivism Framework.

Constructivists situate active play at the center of how young children gain knowledge. The theoretical framework of constructivism is useful to this study because it explains how students learn mathematics and identifies the importance of play for young children (Heddens, Speer, Brahier, 2009). Learning is a personal experience in which students connect new knowledge to their own individual experiences (Post, 1988). The prior knowledge and personal experience of each individual creates a valuable framework for intellectual growth; this learner-centered environment creates a richer context for learning. A mathematical curriculum developed using constructivist principles would be bursting with interactive opportunities for students to explore. Interaction with other students in a collaborative setting, such as group work, would be
favorable to this learning style. In addition, interaction with technology or manipulatives would help form beneficial connections to mathematics (Heddens, Speer, & Brahier, 2009). This learning atmosphere would contain massive amounts of hands-on activities and real-world applications (Post, 1988).

Free play provides a “risk-free environment, rich in mathematics, science, and language that allows all children the liberty to make mistakes to learn” (Heddens, Speer & Brahier, 2009, p. 15). Constructivism’s curriculum and pedagogy have long observed play as a critical element in children’s learning (Dockett & Perry, 2010). As noted above, play is at the center of children’s learning process and is effective for learning mathematics (Hunting, 2010). However, digital technology games are “the first qualitatively different form of play” in hundreds of years and deserve particular attention regarding their position in children’s lives and learning (Salonius-Pasternack & Gelford, 2005, p. 6). Furthermore, although there is growing research on technology and play in different educational populations, once again, few studies have examined young children specifically (Spencer, 2013). As the use of iPads in classrooms are becoming more prevalent, research is needed to document this play and its interaction with and impact on learning. Therefore, this research observed the impact on children of playing with number sense apps on iPads.

The main sources of knowledge before preschool and kindergarten are naturalistic and informal opportunities. Conceptual knowledge and understanding is important for the advancement of mathematical abilities. Charlesworth asserts “concepts are the building blocks of knowledge” (2005, p. 230). Children acquire conceptual knowledge in three main settings: naturalistic, informal, and structured. Naturalistic play is highlighted in constructivism theory and is the most common avenue for learning in the naturalistic setting. Children investigate and
learn through their experiences without outside interference. Playing with shapes and building blocks provides opportunities to learn multiple skills (Charlesworth, 2005). Additionally, researchers have found that virtual manipulatives operated on a computer can be equally or more effective in fostering learning (Clements & McMillen, 1996). The second type of learning is informal learning. This type of learning is accomplished when a person or a technological device asks the child questions or makes comments that increase the knowledge gained by the child in the naturalistic setting. Questions and comments that involve terms such as bigger, smaller, fewer, and more are engaging questions that help children explore and compare. The third type of learning is structured learning. This type of learning involves lessons or activities that help children explore and gain knowledge in specific areas. Structured learning can take place individually with a child or in groups. Although some structured learning occurs early in childhood, the majority of learning occurs in naturalistic and informal settings for young children (Charlesworth, 2005).

This research observed, investigated, and detailed interaction between elementary students and virtual manipulatives in number sense apps played on the iPad and discussed related findings. The learning process of students were described in detail to provide insight on the impact of the iPad on number sense using game-based apps. A constructivist theoretical framework is important because children will be learning number sense through playing with iPad applications. Constructivism can guide a discussion of the findings by supporting a conversation about how students construct mathematical concepts through interactive play with the iPad.
Modern educational practices framed with constructivist principles are encouraged in teaching practices in the classroom (Paily, 2013). Contemporary instructional strategies that incorporate technology must also consider traditional learning theories (Ally, 2004). Even though digital learning is taking place with the aid of a technological device, the educator must recognize learning situations within these environments and encompass traditional learning constructs to provide meaningful, positive active learning. As technology has progressed, emphasis on different learning theories has shifted. Three main educational learning theories have been applied to online learning in the past: behaviorism, cognitivism, and constructivism. Frequently used terms for online learning include “e-learning, Internet learning, distributed learning, networked learning, tele-learning, virtual learning, computer-assisted learning, web-based learning, and distance learning” (Ally, 2004, p. 16). While mobile learning is achieved via smaller devices such as the iPad, it utilizes the ability to access the internet as well as features and programs similar to online learning (Henderson & Yeow, 2012). Mobile learning can be defined as timely, flexible learning occurring in a digital space with consideration paid to the learner’s needs (Melhuish & Fallon, 2010).

Online learning materials have included principles from all three theories (Ally, 2004). Behaviorism, influenced by Skinner, Payloy, and Thorndike, suggests that learning occurs through observable behaviors by external stimuli in the learners’ environment. Most computer-assisted instruction (CAI) technologies were designed with a behaviorist approach. These approaches provide sequential steps of instruction to mathematical problems for the student to observe. Cognitive theorists believe learning is an internal process that heavily relies on the processing abilities of the learner. Memory, motivation, thinking, and reflection play a large part
in the learning process (Craik & Lockhart, 1972). Constructivism, as described in detail above, believes that knowledge is constructed through personal experiences. Individuals gain understanding through observation, processing, and interpretation (Cooper, 1993).

The development of Information and Communication Technology (ICT) fosters a closer alignment with constructivist principles because it offers access to enormous amounts of authentic data, stimulates meaningful interactions with curriculum, and has the ability to supply collaborative spaces for students to communicate (Paily, 2013). Wireless interconnected handheld devices like the iPad have introduced a space that favors constructivism and collaboration in order to achieve understanding of new knowledge (Zurita & Nussbaum, 2004). It is only lately that educational technologies have had the ability to support constructivist methods. The portability of small devices makes them easier to use in social collaboration than former computer system designs, which were made of a single student working space (Henderson & Yeow, 2012). Additionally, having portability allows students to explore personal interests in a discipline at any particular time or location (de Sá, & Carriço, 2007). Moreover, there is more social application software available to enhance opportunities for communication and collaboration than ever before (Henderson & Yeow, 2012). The multi-touch screen of the iPad's interface enables direct interaction between the child and the content, thus promoting longer engagement opportunities for learning (Agostini, Di Biase, & Loregian, 2010).

The learning interactions with mobile technologies align with constructivist principles of real world learning by offering real time feedback on a variety of contextual learning materials (Leichtenstern, André, & Vogt, 2007). Mobile devices support constructivist principles by providing students “with a share of the necessary information to accomplish” an educational objective (Zurita & Nussbaum, 2004, p. 236). Each student often gathers available information
and applies prior knowledge, as well as builds knowledge from others’ shared information. In addition, handhelds can provide mechanisms that ensure all students’ participation in answering questions and decision-making within a group context (Zurita & Nussbaum, 2004).

Nevertheless, mobile learning is distinctly different than previous technology-supported learning models in its method of delivery and facilitation of learning experiences (Peters, 2009). Since iPads are mobile devices, it is appropriate to highlight what affordances for education mobile learning offers to the learning environment. Mobile devices are seen as supporting a liberalization of learning, created by their ability to connect students with each other to create, retrieve, and sustain collaborative learning (Traxler, 2010). Mobile learning provides a unique learning experience in that students negotiate meaning for themselves, with ubiquitous access to information on a portable handheld device, making for a distinct learning form (Peng et al., 2009). Mobile learning is able to decentralize our learning experience (Johnson, Levine, Smith, & Stone, 2010). Mobile learning is beneficial to the learning process because it provides interactive tools within multiple contexts for exploration and collaboration (Sharples, 2009). Mobile learning extends personalized learning experiences by supporting the specific scaffolding needs of a user in their progression of learning (Peters, 2009).

John Dewey’s Experimental Theory

One theoretical foundation to consider when exploring the implementation of iPads using number sense apps in the pre-school classroom could be supported by John Dewey's experimental theory. Most of Dewey’s educational theories appear in his works. Dewey is associated with the founding of the progressive school movement, which used different methods of teaching than traditional classroom methods of his time. Progressive education promotes student-centered activities rather than teacher-directed, teacher-led lessons. The pedagogical
thinking between the 1920s and 1930s is similar to the pedagogical teaching practices of constructivism (Ravitch, 2001).

Both progressive and constructivist principles are solidly grounded in the leading approaches suggested by the National Council of Mathematics (Ravitch, 2001). These movements influenced different types of teaching strategies that emphasized experiences that supported expression and the development of individuality. Opposing traditional methods, these strategies incorporate free activity into the learning process and emphasize curriculum with a direct vital appeal to students. Learning through experience is a critical impression this educational movement fostered.

Dewey considers the importance of the students’ experiences in learning to be critical to the learning process (Dewey, 1938). Dewey states that “all genuine education comes about through experiences,” but clarifies that not all experiences in education are equally educative (Dewey, 1938, p. 25). John Dewey was a leading proponent in this educational movement who designed ground-breaking educational methods. Dewey emphasizes the importance of an interactive learning process (Dewey, 1938): "High-quality mathematics throughout early childhood does not involve pushing elementary arithmetic onto younger children. Instead, successful education allows children to experience mathematics as they play in and explore their world” (Clements & Sarama 2014, p. 2).

The following paragraph highlights how the experiences of children impact learning by the iPad's implementation. Several studies indicate that learning materials provided through an iPad or other mobile devices stimulate engagement with the content and motivation in the learner (Spencer, 2013; Henderson & Yeow, 2012; Manuguerra, & Petocz, 2011). Additionally, the iPad provides more interactive elements and accessibility to educational applications than ever before,
offering a different platform in which children's learning experiences can occur (Melhusih & Fallon, 2010; Peng et al., 2009). iPads can access simulation programs, which give visual representations. Simulation programs present digitally, with interactive components, to represent real world content that provides constructivist related learning principles (Windschitl, 1995). iPad apps can also promote learning through experience by allowing students to create and develop personal content through features such as voice recording as well as taking videos and pictures (Attard & Northcote, 2012). All these features of iPads enrich student learning experiences for the maximization of learning and echo the principles set forth by Dewey.

Lev Vygotsky and Constructivist Principles

Important to the study of how children learn is social constructivism, which builds on constructivist principles. Lev Vygotsky, a popular Russian psychologist (1896-1934), notes that social interaction with others as well as culture influences the mental development of children. He claims that children assemble knowledge through experiences in social settings (Daniels, 1996). Vygotsky also argues that experiences, both encouraging and discouraging, impact the cognitive capabilities of the learners (as cited in Heddens, Speer & Brahier, 2009). Interaction shapes and allows for the construction of new schema in thinking and conduct (Moffett, 2010). Additionally, children gain new knowledge centered on the understanding of contributions of information from each group member (Vygotsky, 1978). These interactions give students a platform in which to question, survey, explain, examine, and clarify previous, current, or future thoughts (Moffett, 2010). Vygotsky argues that mathematics, science, and language offer individuals a setting wherein children can engage in uninhibited play, and it is within this environment that children learn (Heddens, Speer & Brahier, 2009).
Research gathered from collaborative learning studies (Mandryk et al., 2001) as well as constructivist learning environments (Clements & Battista, 1990) presents that children perceive their peers as resources for gaining knowledge and help. The opportunity to collaborate and establish common ideas and social skills, while participating in teamwork on a mutual objective, is encouraged in these types of learning settings. Additionally, being part of a group can increase children’s self-esteem. By being active participants rather than passive listeners, children will enjoy and learn more. This idea relates to the importance of this research being conducted in groups. Allowing children to share thoughts and articulate ideas to each other facilitates a more meaningful learning environment.

Two fundamental concepts expressed in Vygotsky’s educational theories are the zones of actual and proximal development. The actual development zone is the current level of intelligence displayed by the child. The proximal development zone is the level of potential understanding that the student can achieve (Heddens, Speer & Brahier, 2009). This idea relates to the importance of selecting the level of iPad application for the child. Vygotsky declared that all higher-order thinking originated from social relationships. These theories were of interest to the educational community because they helped define what kind of instruction should be delivered to children. Instructors should tie teaching to the potential level of development in a child, rather than to the actual level of development. The potential level of development can be fostered by leading questions, examples, explanations, and illustrations (Daniels, 1996).

Teacher or peer interaction that helps a child in the zone of proximal development understanding is often referred to as scaffolding. Scaffolding is the process of assisting in the development of a child’s learning process. Scaffolding can build upon or activate prior knowledge that the students acquired in the past. For example, the use of scaffolding can be seen
in some of the immediate feedback features of iPad applications. For instance, on the app
*MathSelf*, when students are sequencing numbers 1, 2, 3, 4, and 5, if the child only gets 1, 3, and 5 in the correct spot, the app will help the student by showing which numbers are incorrect. Then the child can try again to correctly arrange the sequence. Children who are challenged by the curriculum will benefit by working with others rather than in isolation. The opportunity to clarify and construct meaning with others increases knowledge and improves problem-solving abilities.

One could make the same argument for collaborative learning, which Vygotsky favors, over isolated repetitive tasks. A mathematical curriculum developed using Vygotsky's constructivist principles would include robust interactive opportunities for students to explore. Today’s iPad apps provide virtual manipulatives for student interaction. Interaction with other students in a collaborative setting, such as group work, would be favorable to this learning style. Wide arrays of strengths are improved when working in collaborative groups (Moffett, 2010), such as content knowledge development, critical thinking, and the transference and recall of subjects. In addition, interaction with technology or manipulatives would help form beneficial connections to mathematics (Heddens, Speer & Brahier, 2009). This learning atmosphere would contain a significant amount of hands-on activities and real-world applications (Post, 1988).

Much of the literature on technology directly links technology with the ability to provide collaborative settings that foster educational virtual communities (Paily, 2013). Although online virtual communities will not be integrated into the proposed study, students will be working together in conjunction with iPads. Handhelds’ features allow facilitation between students’ interactivity and positive interdependence to create collaborative actions (Dillenbourg, 1999). The social constructivism theory is more relevant to the proposed study because half of the participants in phase two of the design will work in small groups. This will support a
collaborative interaction with iPads and classmates to gain knowledge of number sense. To successfully construct groups for an educational collaborative activity, social interaction should be fostered by setting well-defined objectives. Also, roles and rules should be set for the activity. Groups should be made up of two or three students in an appropriate setting (Dillenbourg, 1999).

Jean Piaget’s Theory

It is because of Piaget’s work that educators know young children learn best when they are taught through manipulatives instead of abstract concepts or symbols (Ginsberg & Opper, 1988). Piaget encourages curriculums filled with opportunities to perform an operation on an object. Hands-on activities with measurement, weight, volume and distance would be described as effective ways to teach these mathematical concepts. The action of performing these tasks allows the construction of thought and learning to accrue. Mathematical concepts that can be presented to the student in a more concrete manner will allow a clearer understanding for the child to prevail and build stronger cognitive schema. Piaget consistently suggests meaningful tasks with real world characteristics. Effective mathematics learning using constructivist principles include action (Moffett, 2010).

The overall course of learning depends on the mathematical experiences a child has in their environment and culture. Children’s experiences within their environment can positively or negatively affect the foundation of their mathematical learning. Consistency of developmental progression and instruction works best when instruction considers and aligns with the natural progression of learning in children. Learning requires objectives that correspond to different levels of cognitive development. The instantiation of hypothetical learning trajectories is accomplished through social interactions between teacher and students during instruction on mathematical concepts (Clements & Sarama, 2007). Piaget argues that children must have action
in their environment to gain development in schemata. It is through interaction with their surroundings, using their sensory skills such as seeing, touching, hearing, smelling, and tasting, that children are stimulated to assimilate and accommodate. Piaget recognizes three knowledge categories: physical, logical-mathematical, and social-arbitrary. In the physical, a child discovers properties such as color, weight, and size by physically handling an object. Logical-mathematical knowledge concepts like counting are promoted by the manipulation of objects that can be grouped and counted. Modern technologies are a natural way to achieve Piaget’s ideas of logical mathematical knowledge. Young children love to group and count different objects in their environment. Social-arbitrary knowledge relates to human and cultural rules, regulations, morals, ethics, and dialects (Wadsworth, 1971).

In Piaget’s theory, specific psychological structures which help an individual to organize and make sense of experiences are referred to as schema. These schemas develop and change as an individual’s age changes and their experience in life continues. Piaget’s most known contribution to education is his theory on the developmental stages of intelligence that children must go through in order to learn. The stages are sensorimotor, preoperational, concrete operational and formal operational (Post, 1988). Teachers need understanding of how children construct meaning in learning in order to set appropriate cognitive activities in a lesson. Sensorimotor is the first of the cognitive developmental stages, occurring in the first two years of a child’s life. In this stage, children embrace the world with sensory skills; it is a preverbal and pre-symbolic consistent stage of development. Sensorimotor behaviors are needed for and instrumental in future cognitive development. Children build onto schemata, so at any age, prior behavior and knowledge helps in the growth of intelligence (Wadsworth, 1971). In order for the child to learn in the sensorimotor stage, the child must carry out action in order to create
schemata. The transition between the sensorimotor stage and the preoperational stage is the ability for the child to internalize stimuli and solve problems in their head by using representations of events and not actually carrying them out (Wadsworth, 1971). As the child moves away from the sensorimotor stage, the child begins to show evidence of thinking. In this stage the child selects a more cognitive way of thinking about the world around them. Children begin to use mental representation, internal depiction of knowledge often in the form of an image or concept that the mind can manipulate (Berk, 2003).

According to Piaget’s theory the process of building schemas is called adaptation. Children interact directly with the environment and then build schemas through assimilation and accommodation. The part of adaptation in which individuals use existing schemes to interpret the world is assimilation. The part of adaptation in which individuals change old schemas and make new schema to better fine the environment is called accommodation (Berk, 2003). Children would be using assimilation and accommodation when playing with the number sense apps to learn number concepts.

The preoperational stage is the most important stage in relation to this study because it concerns 4-5-year-old children. The preoperational stage starts at the age of two and continues to age seven. In this period of time, children learn how to develop the ability to represent objects and events. Representation can be developed in deferred imitation, symbolic play, drawing, and spoken language. Deferred imitation is the child's ability to remember a prior behavior. For example, a child playing patty cake alone is remembering a prior action and imitating it. Symbolic play is the world that the child creates in the imaginary and pretend. It is self-motivated activity in which a child does not have to communicate with anyone, but it is an opportunity for the child to engage ideas, thoughts, and concepts. Drawing starts out as doodling
but, as time unfolds, drawing becomes more realistic. Critical learning of symbols and signs becomes understood in the context of the real world.

One of the most significant abilities learned in this stage is that of language. Language begins with one word, then builds into phrases and sentences. In this stage, a child can be egocentric and nonsocial. However, towards the end of this stage conversation becomes both communicative and social (Wadsworth, 1971). A classic conversation of numbers in this stage would be asking a child to represent two rolls of checkers with equal lengths. After the child constructs the rolls visually, the length looks the same, but the number of checkers in each row is usually not the same amount (Heddens, Speer & Brahier, 2009).

In the concrete operational stage, which includes ages seven to eleven, one of Piaget’s fundamental concepts in developing knowledge is that of operation. This is the process that engages a child to take action on an object in the real world. In this stage, the child should be able to position a set of objects by weight from least to greatest. During this stage, students can manipulate objects, think critically, understand conversation and pose the ability to consider other views (Heddens, Speer & Brahier, 2009). The final stage in cognitive development is formal operation, which begins at the age of eleven. In this stage, individuals have reasoning, reflection, hypotheses, analysis, an understanding of cause and effect, and abstract logical thoughts to build understanding on (Heddens, Speer & Brahier, 2009). Piaget’s developmental stages of intelligence are important to this research because they are a traditional learning trajectory that helps identify the stage of development and appropriate tasks for student learning at 3-5 years of age.
Artifact-Centric Activity Theory

There have been attempts to better understand the process involved with student learning on modern technology devices based on constructivist principles. Before the age of the direct touch screen interface, children controlled the movement of virtual manipulatives through indirect devices such a keyboard or mouse. However, technological devices like the iPad allow for direct and multiple touch commands, allowing for easy movements of virtual manipulatives. Virtual illustrations are simple to display in terms of representation; an example of this would be a virtual base ten set of manipulatives. These easy to use manipulatives open a new platform for learning for early elementary-age children. Never before could a child directly interact with manipulatives in such a first-hand fashion.

Ladel and Kortenkamp (2013) present the activity theory and shows how it can describe the complicated circumstances that arise when children utilize up-to-date technology, such as apps on iPads, devices which allow the child to directly operate and control the technology programs and interact with manipulatives. The article showed the learning environment of the artifact-centric theory through different applications related to various topics, such as part-whole concepts and base ten blocks mentioned above. The authors then focused on the “artifact,” the technological device, which has infinite options for transforming the learning of math. This thought of focusing on the technology as the center of learning leads the authors to the artifact-centric activity theory. Establishing and developing this theory, artifact-centric theory, provided a framework for analyzing early childhood technology learning environments in mathematics education. It is important to note that the article observed obvious characteristics of why the use of direct touch interface technology should be used with small children:
(1) The user interface is easy to understand *(sometimes even natural)* and should not add unnecessary complexity to the learning process; (2) The direct manipulation enables children to work with virtual manipulatives directly instead of being mediated through another input device; (3) It is possible to create environments with large screens (like multi-touch-tables) that encourage collaborative learning and communication of the children. *(Ladel & Kortenkamp, 2013, p. 1)*

Ladel and Kortenkamp’s theoretical framework the artifact-centric activity theory is provided below in Figure 1; the diagram was modified from Engestrom *(1991)*.

\[\text{Figure 1 - The artifact-centric activity theory (Engestrom, 1991). This depicts interplay between subject, artifact, and virtual manipulatives.}\]

The middle of the diagram explains the main alignment of interactions, which consists of the subject, the artifact, and the object. The subject represents the children working with the artifact, which would be the touch screen technology, and the objects. The objects are displayed
through the artifact, which illustrates them in appropriate virtual manipulatives or virtual representations. The article goes on to describe “externalizing” and “internalization” which are used on the diagram to explain the interaction between most important stages in the overall theory, which include subject, artifact, objects, rules, and group. Traditionally, in the mathematics discipline and in mathematics education, models are created for abstractions and have corresponding rules. Ladel and Kortenkamp (2013) explain that “[t]hrough the rules we define the object formally (externalizing it) and the rules are made to capture the nature of the object in the best way possible (internalization)” (p. 2). The theory takes into consideration the element of group work since the multi-touch-tables are seen as having positive benefits to working in groups. Because the device can be connected to a projector and displayed on a bigger screen, students can more easily access the device without taking turns with a mouse.

One reason the artifact-centric activity theory was selected for this study’s theoretical framework was because it describes interactions that can occur with number representations and touch counts by students. This theory considers how numbers and quantity can be rearranged by students or animated by mathematics software to generate more meaningful understanding for children. For example, a task on an iPad app asks a student to add 5 + 6. This theory takes into account how the quantity of 5 + 6 could be rearranged to see the problem as 10 + 1 = 11 by taking the 6 and grouping 5 units of the 6 with the other 5, resulting in 10 +1. This type of regrouping was illustrated within ST Math’s sub-game “Alien Capture,” wherein students begin learning numbers 10-20. For example, the number 15 might be rearranged for the child to see 15 as 10 +5. Additionally, this type of rearranging of numbers was seen in the simple addition and subtraction problems within the ST Math app.
Previous Studies on Technology Integration and Young Learners

**Interventions for young children.** Young children who exhibit difficulties with learning and understanding mathematics concepts often require interventions (Kroesbergen & Van Luit, 2003). Remediation has proven to have encouraging and positive impacts on improving mathematics achievement (Fuchs et al., 2006). Children in kindergarten who demonstrate low number sense competencies and phonological skills had rapid development using mathematics intervention, signifying the importance of intervention with early elementary numerical skills (Vukovic, 2012). The bulk of interventions designed for three-to-five year-old children is intended to aid children who are at-risk for academic failure (Dowker, 2009). Mathematics interventions used with young children or children at risk have mainly consisted of integrating mathematics opportunities throughout the school day (Arnold, Fisher, Doctoroff, & Dobbs, 2002). These interventions can be implemented in a variety of ways and through a wide array of teaching methods, including games. In the context of play, interventions with real world mathematics problems or contextual situations can be successful for children (Hanline, Milton, & Phelps, 2010; Vandermaas-Peeler, Newman, & Bumpass, 2007). Intervention for young children can be collaborative through peer tutoring (Fuchs, Fuchs, & Karns, 2001). Computer-assisted instruction can be a meaningful intervention to improve mathematics understanding (Baroody, Eiland, & Thompson, 2009; Fuchs et al., 2006).

Even though the bulk of computer-assisted instruction research conducted so far has been with older elementary students (Fuchs et al., 2006), some research has looked at the positive effects and benefits of the impact of such technology on young children while learning math. These studies suggest improved motivation for academic work and creative mathematics thinking (Clements & Sarama, 2003). Other research has found that using the *Everyday*
Mathematics curriculum with the discovery-learning computer-assisted instruction in a Head Start setting can significantly improve number sense. The technology intervention would need to be intensively integrated, focused on small groups, and used for individual tutoring (Baroody, Eiland, and Thompson, 2009). Sarama & Clements (2009), state that computer assisted instruction can be beneficial because it allows a child to maneuver and alter virtual manipulatives.

Past research on computer-assisted teaching, integrated learning systems, and information and communication technology. Since mathematics apps on the iPad are new educational technology tools available in the preschool and elementary settings, there is limited research on the topic (Spencer, 2013). However, researchers could look at past research efforts with computer-assisted instruction (CAI) to provide beneficial evidence and support for further investigation of the iPad. It is seen that, through the progression of technology implementation there have been consistent benefits for learning. CAI programs have been the primary technology used in the education classrooms to assist instruction (Jonassen, 1994). Slavin and Lake (2008) discussed CAI classrooms as having longstanding methods to enhance elementary students’ mathematics performance. Overall, in the report, CAI environments were found to have moderate effects in the teaching and learning of math. The greatest effects of CAI were found in the instructional practices, such as collaboration, engagement and drive, supplemental tutoring practices, and classroom organization (Slavin et al., 2008).

Over the years, CAI developed from programs that offer practice problems to complex integrated learning systems (ILS) which can evaluate students’ levels and then align the student with appropriate instruction. Normally, CAI programs are used several times a week to supplement classroom instruction. CAI programs are beneficial for identifying students’
strengths and weakness, then providing self-instructional practice problems to help with mastery of mathematics content. In mathematics, a discipline rooted in progressive skill-building, this could be significant. Most of the high-quality studies took place during the 1980s and 1990s (Slavin et al., 2008). However, the CAI programs followed more of behaviorist instructional strategies in that students would often observe a set of instructional sequences in solving problems (Jonassen, 1994).

While both significant and insignificant findings have been associated with CAI, this next paragraph will highlight the positive effects found. CAI programs have been proven to have an effect on both mathematics and reading, although much larger effects have been found in mathematics (Murphy et al., 2002). Jostens Learning System, currently called Compass Learning, offers progressive curriculum in subjects such as mathematics and English. These lessons coordinate with standardized test questions, regional goals, and classroom objectives. When using Jostens, significant positive effects were found in mathematics for grades 4-6 (Zollman, Oldman, & Wyrick, 1989).

Another integrated learning system, Success Marker, developed by Computer Curriculum Corporation (CCC) and sold by Pearson Digital Learning, provides both an organization and evaluation system simultaneously. This technology was developed to supplement classroom instruction by offering drill and practice problems. A randomized three-year longitudinal study in four Los Angeles schools found strong positive effects on mathematics concepts comprehension when looking across grades 2, 4, and 6 for students using Computer Curriculum Corporation (Ragosta, 1983). Another randomized study using CCC software in impoverished schools located in Louisiana found that grades 3-6 using the software had significantly higher mathematics scores from pre-test to post-test (Hotard & Cortez, 1983). Students using Success
Maker performed better on the Stanford Achievement Test following the software’s introduction (Laub, 1995).

One more program, Accelerated Math, is a computer-managed learning system that identifies students’ weaknesses and strengths, then assigns exercises and reports the students’ success back to the teacher. The program is often used to supplement instruction and emphasizes abilities and computations. It is designed to be used alongside traditional or reformed mathematics materials. One study found small differences on the Northwest Achievement Test when using Accelerated Mathematics in Minneapolis (Ysseldyke et al., 2003). In addition, another study reported higher scores on within-school and district comparisons when implementing Accelerated Mathematics into the curriculum (Spicuzza et al., 2001).

Kulik (2003) reported specifically on integrated learning systems (ILS), which utilize tutorial instruction in the mathematics classroom. He summarized research about the effectiveness of ILS by looking at sixteen controlled studies conducted in the last decade. He found that, in all sixteen studies, there was a slight increase in mathematic achievement when ILS were used. In nine of the studies, the ILS produced a statistical significance effect and were considered to be educationally meaningful. Within these sixteen studies, nine studies used ILS for instruction in mathematics only and seven of the studies gave instruction using the ILS in both reading and math. It was concluded that ILS effects were greater in the studies that only used them for mathematics. Additionally, Kulik maintains that instructional technologies repeatedly improve teaching programs in mathematics. He discusses that ILS have produced positive effects from 1970s to 1990s (Kulik, 2003).

**Information and communication technology.** Another traditional technology used in the educational classroom is Information and Communications Technology (ICT). Normally,
ICT has been provided through personal computers in a computer lab setting away from the normal teaching classroom. ICT offers more constructivist approaches for teaching and learning than previous technological tools. ICT provides access to the internet, which offers intense resources of authentic information. Also, ICT that provides access to the web assists students with meaningful interactions with content and provides collaborative features in which individuals can respond to each other. This digital environment provides authenticity and social collaboration to promote a constructivist learning environment (Jonassen, 1999). Examples of these environments could include wikis, blogs, collaborative graphics aids, E-portfolios, virtual learning environments and, document and multimedia sharing (Paily, 2013). When designing a constructivist learning environment, the following components should be incorporated: students must conceptualize the problem, then interpret and develop answers to the problem. The learning environment, in this Case the World Wide Web, should provide appropriate information for the student to solve the problem. Cognitive tools should be supplied by the web for learners to understand the problem (Jonassen, 1999). Conversation should be supported with collaborative tools such as e-mail, chat, instant messaging, or forums (Paily, 2013). Recently, smaller mobile devices like laptops, tablets, and iPads have been evaluated and implemented in the classroom as tools to supplement students’ educational lessons (Mifsud, 2002).

**Description of technology focus.**

**Supporting research for iPad implementation.** One recent study, which incorporated experimental game-based learning apps for a five-week period, showed enhanced engagement and motivation to learn. In addition, this research indicated development of cognitive skills and enhanced learning approaches (Lin & Pow, 2011). It should be noted that employment of game-based learning as a teaching tool is in its initial stages of development (Mansour & El-Said,
2009). It has been suggested that real world applications connected to mathematics could be taught through interactive games. Additionally, young children normally enjoy educational games and engage with mathematics concepts when playing them (Griffin, 2007). The iPad had a variety of instructional mathematical game applications and virtual manipulative applications for maximized learning. Students will benefit from additional exposure to mathematics through game-based learning using iPad applications (Griffin, 2007). Mathematics games are used to improve engagement, motivation, and students’ learning (Clark & Ernst, 2009). Since there is not a well-developed picture of how game-based apps can impact cognitive development of mathematics concepts with young learners, further research is needed to investigate and observe children playing with number sense game-based iPad apps.

A recent study has examined the value of implementing the iPad to aid children’s learning of numeracy development, specifically recognizing and quantifying numbers 1 through 10. This research looks at how iPad integration affects self-efficacy and motivation concerning number sense (Spencer, 2013). The study, which took place in Dubai, included 160 young learners. The iPad application that was used during this study is called *Know Number Free* by Lookkid Software. This application is intended to help children recognize and count numbers. Children were provided with tracing and writing activities. After a certain mastery level of recognizing and counting was attained, the app provided more number-games and activities. This app was chosen because it was easy to operate with clear visual number representation and numeral symbols. Furthermore, it highlighted digit skills that teachers suggested needed improvement (Spencer, 2013). In this study, there were two groups; one group used iPads for the first six days of the investigation, while the other group did not. Then, at the mid-point, group one did not use iPads while group two did use iPads for the remaining five days. Both the
experiment group (group one) and control group (group two) showed improvement in numeracy after iPads were introduced. Both groups showed improvement during the time they used iPads for educational play. In conclusion, data provided evidence that a short time of exposure to the iPad can impact significant learning gains in numeracy. The findings indicated that children in early elementary years are naturally engaged with play-based content and further research is needed to adequately evaluate the impact of iPads and their effects on the learning process (Spencer, 2013).

Attard and Curry (2012) analyzed how iPad implementation affects both teaching and student engagement. In the finding, it was concluded that teachers and students perceived the engagement of mathematics to be increased by the use of the iPad. Some elementary students reported cognitive engagement through challenging problems framed in a game environment. Both the teacher and students commented on the benefits of instant feedback. Additionally, the iPad allowed for the implementation of a wide variety of teaching methods that encouraged student-centered activities, which were perceived to have successful engagement features for students. Students reported having a good experience with learning on iPads. The teachers reported increased student excitement and participation throughout mathematics tasks (Attard & Curry, 2012).

Another research project examined the impact of a 1:1 iPad initiative in two fifth-grade elementary schools in Virginia. One school had 48 fifth-grade student participants and the other school had 56 fifth-grade student participants. This quantitative, quasi-experimental study explored iPads in a 1:1 nine weeks technology initiative in two rural Virginia fifth grade classrooms. The nonequivalent group design aligned scores from the fifth-grade mathematics SFAW Virginia SOL pre-test and post-test assessments to establish the influence of iPad use, if
any, on fifth-grade students’ mathematic achievement. The research found that experiences with iPads did not significantly influence student achievement (Carr, 2012). However, the researchers suggest longer studies are needed to observe the implementation of iPads. Also recommended was incorporating the iPad and using different mathematics applications. Additionally, different grade levels should be investigated using the iPads (Car, 2012).

**Affordances and constraints.** In this study, observation of qualitative video data which records touch counts, and student interactions was used to identify affordances and constraints accessed by preschoolers when playing with each app. Identification and evaluation of both affordances and constraints among the apps was conducted. Affordances can be broadly understood as the interplay between an object and an agent (Norman, 2013). Key to this understanding is an emphasis on interplay; what may be an affordance for some may not be for others, depending on the student’s ability. This reinforces the research design of purposeful selection of participants at varying levels of mathematics ability and technology experience: to gain a holistic understanding of what affordances and constraints are accessed by different types of students. An analysis of accessed affordances and constraints in conjunction with student performance may yield fruitful insight on what affordances and constraints foster the learning of number sense.

In a general sense, affordances and constraints are connected to design and, ideally, the intuitive interaction between the user and the object. A door’s design, for example, should imply how to use it without direction or assistance (Norman, 2013). Affordances and constraints are not specific to digital platforms; everyday objects provide affordances and constraints, too.

Burlamaqui and Dong (2014), describe affordances as “cues for the potential uses of an artifact (iPad apps) by an agent (Pre-schooler) in a given environment” (p.13). While the iPad
has its own affordances, which include portability, social interactivity, and computing power (Klopfer & Squire, 2008; Pea & Maldonado, 2006), these should not be confused with the specific affordances provided within each number sense app. Affordances create opportunities for action, hinting at the ways in which an in-app element can be utilized and its capacity to act. Gibson (1986) wrote that affordances can either be helpful (beneficial to the user) or hindering (delineating restrictions and providing structure for action) (p. 137). The relative help attributes of supporting features can be classified as affordances (Gibson, 1986) and constraints (Greeno, 1998). Furthermore, this research uses the term “access” in regard to affordances and constraints, building on Patricia S. Moyer-Packenham et al (2016)’s research involving preschool-aged children and number sense apps, which uses “access” to describe children’s observable interactions with the possibilities presented by an app’s affordance.

As this doctoral committee begins to embrace the concepts of affordances and constraints as they pertain to this dissertation proposal, the author would like to begin with an illustration to consider. When thinking about what a normal classroom teacher does to orchestrate learning for students to help bridge their understanding or knowledge of a subject, a teacher often uses different types of teaching elements such as visual hints, reminders, questions, explanations, illustrations, collaborative groups, different manipulatives, and resources in an effort to help students learn (Kennewell, 2001). These classroom elements are akin to the supporting features available in digital platforms for learning; where the teacher has a lesson plan and activities, a number sense iPad app has built-in content. Aspects of this content can be categorized as either affordances (Gibson, 1986), which stimulate action on the part of the learner, or constraints (Greeno, 1998), which provide direction and structure for that action. Alongside an investigation
of content and the affordances and constraints an app’s content provides, individual ability must be taken into consideration (Kennewell, 2001).

To illuminate this phenomenon and to further connect this research to the lived experience of the researcher, consider an example. An early-elementary-school reading teacher encounters a student who is both a poor reader and speller. She provides the student with a technological device that first identifies misspellings or incorrect diction, then prompts the student to select the appropriate word and spelling from a list of likely options. In this scenario, the supplied list of possible correct words would be an affordance because it provides the student with the potential for action (choosing the correct word and continuing the writing assignment); however, this student is not only a poor speller, but also a poor reader. Thus, the student cannot read the provided list of possible words, illustrating the interplay between affordances, constraints, and individual ability. As technology progresses, the device gains a new affordance: reading aloud. Now, when the student is provided a list of potential words, the device reads them aloud, enabling the student to access this affordance for learning, choose the correct word, and complete their writing. The affordance provided, reading aloud, afforded the student the ability to identify the appropriate word.

Although this example was rooted in language arts, this research was interested in the same types of interactions with affordances and constraints for learning within number sense apps’ content. Ultimately, affordances and constraints are of interest because this research sought to understand what affordances and constraints are beneficial for learning, as depicted in the above example. This could additionally provide insights for future app development and design.

Affordances denote an opportunity to act on the part of the agent. For instance, the apps utilized in this study each include sub-apps involving moving visual representations of quantity
to their corresponding numerical symbol. In this case, the app afforded the student with the opportunity to act by providing visual representations of quantity that are, in fact, moveable and should be matched with their appropriate numeral. Moreover, the constraint in this scenario would be the numerical symbol’s immovability. By restricting an agent’s engagement with the app’s material in this way, the constraint provides structure for the user’s action. The app’s restriction of action thus works to direct the user towards the appropriate (and available) action. Some of the available affordances found in the three apps of interest to this research include: pronouncing the written symbol after it is traced by the student (affords opportunities for student to connect written symbols to verbal pronunciations), connecting the representation of blocks to the written symbol of quantity (affords opportunities to connect representations to written symbols), and clicking feedback as students touch each block (affords cues of one-to-one correspondence). All affordances and constraints fall under one of three categories derived from the multimodality of the iPad: visual, audio, and touch. The codebook contains available affordances for each app see Appendix C.

When children learn with number sense iPad apps, the researcher can observe the processes of their cognitive activity by studying changes in children’s interactions with the device and in what those interactions rely upon (what the device affords) (Piaget, 170). The observation protocol is so written that it captures changes in the students’ interactions with the apps’ content by recording their responses to various math-based tasks, such as identifying numbers 1-10, ordering numbers 1-10, matching quantities 1-10 to numeral representations, as well as overall correct and incorrect answers. In addition to task-based measures, the observation protocol provides a space for the researcher to note more holistic comments about the students’ engagement with the apps, thus providing further insight on affordances and constraints.
This research investigated possibilities for action (affordances) and restrictions on possible actions (constraints) within math-based number sense apps. Ultimately, this research sought to provide insight on what actions or restrictions on available actions help students learn math. The results of this study could work to lay a foundation for further research and facilitate future number concept app design, particularly for preschool-aged students. Figure 2, below, used Kennewell (2001)’s “Influences on classroom activity” as a model to illustrate the complex relationship between student ability, affordances and constraints, and learning as discussed above.
Justification for affordance emphasis in current study. After an extensive literature review involving affordances, the most pertinent and applicable examples in the literature will be discussed. Patricia Moyer-Packenham et al. (2015) investigated the role of affordances in elementary students’ (between the ages of 3 and 8) mathematics educational accomplishments and completion rates using six virtual mathematics manipulatives in a digital platform. The duration of the study was a one-time 30-40-minute interview in which the students were both
observed working with the mathematics apps as well as recorded via their touch counts. The study took on a convergent mixed method design; the qualitative results showed that there was no significant difference in learning performance but there was an improvement in efficiency. The qualitative research focused on affordances and what affordances were accessed by students. Six major affordances were identified; these included both helping and hindering affordances. Additionally, the affordances were analyzed according to which grade level of student accessed a certain kind of affordance. Bullock et al. (2015) observed thirty-five young children’s iPad interactions to study their counting skills. They defined a progression of learning and expectations to note changes in young children’s counting abilities, and the app affordances related to these changes, to promote effective mathematics teaching. Although they did not find significant changes in participants’ counting skills, they did note differences in how each child accessed the available affordances. Moyer-Packenham and Bolyard (2016) looked at the affordances of virtual manipulatives as a means of working towards a more concrete definition of “virtual manipulative.” They found five common virtual manipulative frameworks for educational apps. Finally, Kennewell (2001) laid the groundwork for this research in his research on the complicated relationships between affordances, constraints, learning, student ability, and the classroom environment.

Conceptual Framework

Figure 3, below, encapsulates all of the concepts discussed in chapter two and illustrates their unique relationships with each other in regard to this study.
Figure 3 - Conceptual framework. This figure depicts the relationships between Constructivism and learning.
Figure 4, below, explains the relationships between data collection, artefact-centric theory, and Kennewell’s (2001) affordance and constraint research.
Figure 4 - Conceptual framework and relationships between data collection and technological theoretical frameworks.
Explanation of conceptual framework. The above diagram illustrates the relationship between constructivist theories of learning and this research’s qualitative Case study design. Even though the foundational media of this research is technology, this inquiry still must consider constructivist principles involving young children and theories of learning (Ally, 2004). As is more rigorously discussed later in this chapter, Dewey, Piaget, and Vygotsky are key contributors to theories considering children’s learning and development. Dewey insists upon an awareness of student experience in knowledge construction (Dewey, 1938); Piaget highlights the importance of the individual learner’s cognitive level and corresponding abilities (Piaget, 1964); Vygotsky promotes the critical nature of play, collaboration, and scaffolding in children’s learning (Vygotsky, 1978a). Each of these models of learning influenced this research. This research incorporated constructivist concepts via the following considerations: emphasizing student experience within app learning environments, responding to student skill level within app learning environments, investigating student collaboration and appropriate learning settings, and evaluating the most frequently used affordances and constraints for learning. As is additionally more rigorously discussed later in this chapter, iPads themselves are uniquely situated to facilitate constructivist learning models because of their affordances, including portability, internet access, tactile interaction with virtual manipulatives, individualized learning experiences, and student ownership of learning. Furthermore, each learner’s interaction with the iPad will depend upon their level of ability in both mathematics and technological experience, which is significant to the unique relationship between individual ability and affordances and constraints provided by the learning tool (Kennewell, 2001). This research seeks to look at how the affordances and constraints of the selected iPad number sense apps are used by the students for learning number concepts. It seeks to give insight about what types of interactions with the
iPad are the most frequently performed and show potential to afford the child learning of number concepts.

The experience of the child was considered by selecting peer-reviewed apps with appropriate number sense activities. The apps provided a wide range of activities for young children to learn, practice, and play with number sense concepts. Through the apps, young children are engaged with numbers and provided the opportunity to problem solve, reason, use critical thinking skills, develop cognitive thinking, and engage in self-regulated play. These activities are also associated with learning goals in constructivism (Savery, 1995). Students’ interactions with the apps was captured in this research by videotape, allowing the researcher to gather data on completion of tasks, most frequent affordances and constraints accessed, and the learning environment of one-to-one interactions. The interactions between the student and the number sense apps with was analyzed with the artifact centric activity theory (Ladel & Kortenkamp, 2013) in mind. This research sought to give insight on learning performance and efficiency, the appropriate environment for learning, and accessed affordances and constraints. Gathering qualitative data concerning the student’s interactions with the iPad will provide more details to answer the research questions.
Chapter 3: Explanation of Methodology

This research utilized a qualitative case study to describe what happens when children interact with number sense apps. This study provided insight on 4-5-year olds’ actions performed on the iPad. This chapter discusses the rationale behind conducting a primarily qualitative study with a Case study design. This chapter additionally includes descriptions of the research site, participants, procedures, and data collection instruments. Data collected will include interviews, observations, parent questionnaires, and recorded video screen interactions.

Rationale for Qualitative Methods

Qualitative research uses multiple sources of data to study a phenomenon, including interviews, observations, documents, artifacts, pictures, observation protocols, and audiovisual materials (Creswell, 2007; Yin, 2014; Marshall & Rossman, 2011). The researcher submerges in a natural setting to collect data – in this research case, a charter school in the southwest United States – where the participants experience the phenomenon. The phenomenon of interest in this Case is preschoolers’ use and interaction with number sense mathematics apps to gain knowledge of number concepts. John Creswell (2007) says that qualitative research is important to illustrating complex issues to create understanding. The data is analyzed inductively, establishing emerging themes, categories, and patterns. The final report of the data encapsulates participant voices, researcher reflexivity, a complicated description and evaluation of the issue, and broadens the available research (Creswell, 2007). Marshall and Rossman (2011) identify qualitative research’s goals as: exploration, explanation, description, and emancipation. This research is qualitative in nature because it described and provided a detailed picture of preschoolers’ interactions with number concept apps during routine iPad sessions (three ten-minute sessions a week for fourteen weeks).
Advocated by Merriam (1998), case studies are a common approach of investigation in the field of education. Qualitative researchers collect data that represents the world and lived experiences, including notes from the field, pictures, interviews, audio recordings, and others (Denzin & Lincoln, 2005). Furthermore, qualitative research investigates phenomena in their organic environments, hoping to understand the meanings people attach to them (Denzin & Lincoln, 2005). Bernard and Ryan (2010) emphasize that qualitative research should be applied when the intention of a study is to describe, explore, test, and compare different Cases. An additional purpose for using qualitative research can be to understand a behavior or action and how much it happens. This study deeply investigated app affordances and constraints accessed by preschoolers. It strived to look at the interplay between preschoolers and iPads and documented details of the students’ experiences with the iPads. In this research, “interactions” are loosely understood as what preschoolers do on the iPad apps and how they respond to the apps’ stimuli.

This research is qualitative because it used multiple sources of data to study students’ interactions with number sense apps, including a parent questionnaire, semi-structured interviews with students, observations documented with video recordings, as well as an observation protocol for iPad interactions, field notes, and artifacts. This research took place in the students’ natural classroom setting. Participants’ voices were heard via narrative passages through the coding of transcribed interviews. Video recordings and the observation protocol allowed the researcher to describe how interactions with the number apps change over the course of the fourteen weeks. Figure 5 depicts the cycle of qualitative research.
Figure 5 - Cycle of qualitative research, adapted from Creswell’s (2007) “Qualitative Inquiry and Research Design.”

Rationale for Case Study Methods

Yin (2003) recommends case study methodology be employed if the study focuses on answering “how” and “why” questions. Merriam (1998) promotes qualitative case studies in the discipline of education. Benbasat (1987) discloses that case study research is well-matched for capturing the knowledge of participants. Furthermore, case study strategies can be used to further document the experiences of participants. Additionally, Benbasat (1987) believes case studies are useful for conducting research on phenomena about which little research has been done. Important insights can be obtained through case study research; in the information system field,
this is specifically helpful due to rapid production and new emerging themes each year (Benbasat, Goldstein, Mead, 1987). A case study should focus on creating a detailed description and investigation of an activity or phenomena. Case study types are best suited for offering in-depth understanding of a case with boundaries (Creswell, 2007). Data analysis is completed through Case descriptions and identification of case themes. In this study, data analysis will utilize a systematic approach. Creswell (2007) describes the coding process in a systemic approach to qualitative research as looking “at the number of passages associated with each code as an indicator of participant interest in a code” (Creswell, 2007, p.152). In a formal report, a detailed examination of one or more cases are deliberated upon (Creswell, 2007). A case study is selected to examine “a ‘case,’ bounded in time or place, and look for contextual material about the setting of the ‘case’” (Creswell, 2007 p.96). A case study is deliberately used when a researcher wants to include contextual aspects highly relevant to the phenomena being studied (Yin, 2003). Additionally, case studies are used when the lines between the event and its context are unclear (Yin, 2014). Qualitative case studies offer tools to study complex phenomena occurring in relevant contexts (Baxter & Jack, 2008). In the case of this research, participant knowledge and behaviors as well as phenomenon and context were unclear. The phenomenon of interest, of course, is the student interaction with iPad number sense apps; the boundaries between this phenomenon and its contextual conditions are murky at best. In this research Case, relevant contextual conditions included: at-home technology usage as measured by parent questionnaires, preexisting mathematics ability as measured by the TEMA, and behavior in a natural mathematics classroom setting as measured by observations, field notes, and the collection of artifacts. Data was collected regarding contextual conditions to build descriptive passages for the purposeful selection of research participants. The lack of clarity regarding the
phenomenon of interest and the boundaries between its occurrence and its context make it well suited for qualitative study.

Research Questions

How do 4- to 5-year-old preschoolers interact with mathematics-based number sense iPad apps for learning?

What affordances and constraints are accessed by 4- to 5-year-old preschoolers when interacting with number sense iPad apps, as observed via video recording?

Justification of Questions

The research questions seek to describe what preschoolers do on the iPad when playing number sense apps and exploring the implementation of this new classroom technology. This research aims to describe student interactions with apps to more deeply understand how mathematics-based iPad apps can bolster young learners’ acquisition of number sense concepts. It provided insight on beneficial app affordances and constraints accessed by students and included parental insight on students’ access. These results helped fill the current gaps in mathematics education when considering the implementation of the iPad in a preschool setting and appropriate interactions for learning.

The Role of the Researcher

The researcher (also referred to as the principal investigator) first reviewed relative literature on number sense, technology, and early childhood learning alongside research about iPad classroom implementation. She also read previous studies about how multimodality features in apps afford learning opportunities for students. After the preliminary research phase, the principal investigator went into two preschool classrooms for 14 weeks and collected data via the TEMA, parent questionnaires, semi-structured interviews, artifacts, and video recordings with
both the teachers and students. In total, she spent 144 hours and 41 minutes conducting this research in the field, working with and observing the students in their natural environment, the preschool classroom, from February to May 2018. This research necessitated a significant time investment in order to gather rich descriptive data to provide robust narratives about the participants’ experiences. Furthermore, she gathered nearly 98 hours of video documenting 14 students’ interactions with number sense apps, which helped clarify affordances and constraints accessed by the preschoolers. Since each classroom routinely used ST Math, more videotaping captured interactions with this app than the other apps of interest. In the preschool classroom, the researcher effectively and for all practical purposes became an early childhood teacher, working individually with students on number sense apps. This was a pronounced role that the researcher engaged in during the iPad sessions. The researcher implemented and followed the regular teachers’ established routines with the students and the iPad apps. She acted as the teacher in the iPad sessions, assisting children and helping them learn mathematical concepts using the iPad. The principal investigator imitated the teachers’ instruction by using cards, boxes, or other manipulatives to help break down number concepts for the children and by identifying concepts that challenged students and provided assistance so that the preschooler understood the tasks at hand and progressed in the app. This hands-on approach allowed her to gather rich detailed descriptions about the students’ interactions with the apps. The regular classroom teachers and other research studies emphasize this as an effective strategy to implement when working with computer-assisted instruction (Peterson & Patera, 2006).

Research Site and Target Population

Research site. The research site was a state-funded public charter school providing a college-prep curriculum to students in grades spanning from preschool to eighth grade. The staff
and teachers provided a structured academic environment supported by best teaching practices, problem-solving activities, and critical thinking learning opportunities. Additionally, the curriculum offered rich creative educational instruction focusing on collaboration and communication. The charter school was established for impoverished neighborhoods and is in the metropolitan area of Las Vegas. The school helps provide a high-ranking, tuition-free education to students and parents living in regions of poverty.

Currently, the charter school operates two preschools for four- to five-year-old children. The centers consist of roughly seven classrooms and approximately one hundred preschool students. The preschools operate from the middle of August to the beginning of June on a Monday through Friday 8:30 am to 2:30 pm weekly schedule. The preschool centers are state-funded early educational programs with a lottery-based enrollment process for families with low income eligibility. The preschool curriculum standards focus on preparing preschoolers for kindergarten and six areas are emphasized: art, literacy, mathematics, health, and social studies/social emotional wellness.

The preschool mission states the educational principles employed foster each student in becoming a well-rounded person in hopes of reaching their full potential. Each child is provided with an engaging learning environment. The school staff worked to help the preschoolers grow into self-motivated learners and develop in all areas. The curriculum encouraged a child-centered, play-based learning environment with creative activities to motivate learners.

When specifically looking at children under 18 years of age in Las Vegas, it is reported that 30.5% live in households that receive Supplemental Security Income (SSI), public assistance checks, or nutrition vouchers. The percentage of children living in households whose status has been determined as below poverty level is 25.4% (US Census Bureau, 2015).
The demographics of Las Vegas report the following: 59.1% of the population is white, 11.6% of the population is Black, 0.7% is American Indian and Alaskan Native, and 14.2% are some other race. The Hispanic or Latino population for Las Vegas is 45.1%. (US Census Bureau, 2015). The demographics for the charter school report a large Hispanic population: 52.1% of the student population at the research site is Hispanic, versus a typical Las Vegas school with 47.1 percent. Additionally, demographic data for the charter school reports that 54.5% of students have no-cost lunch, and 17.8% of students have reduced-cost lunch (M. Newman, Personal Communication, May 22, 2018).

**Targeted population.**

*Students.* Students who participated in this study were from different classrooms. Six preschool students were selected by varying mathematics ability scores on the TEMA at low, average, and high levels of ability. These six participants were additionally selected at varying levels of preexisting technology experience, as reported by parents on the parent questionnaire, at novice and experienced levels. One criterion for selection of participants was that only preschoolers 4-5 years of age were eligible for the study. There was a total of twelve participants consisting of eight males and four females. The participants’ ages ranged from five years and two months old to four years and five months old when the research project began. At the end of the research, the participants’ ages ranged from five years and five months old to four years and eight months old. Participants’ parents identified their racial backgrounds; among the twelve, the racial demographics were as follows: one African American student, seven Hispanic students, one Latino student, one Hispanic/Asian student, and two parents who chose not to disclose. From these twelve participants, six were purposefully selected for the research study. Two girls and four boys were selected, including one African American participant, one
Hispanic/Asian participant, one Latino participant, and three Hispanic participants. These preschoolers’ prior iPad experiences and use of technology in the home setting varied. The charter school was selected for this research because it served the preschool population, is in an area with lower economic status, and consisted of a high percentage of students who live in poverty. See Table 1 for participant attributes.

**Table 1 - Participant Attribute Chart.**

<table>
<thead>
<tr>
<th>Student</th>
<th>Age Start</th>
<th>Age End</th>
<th>Gender</th>
<th>Race</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chase</td>
<td>5.4</td>
<td>5.7</td>
<td>Male</td>
<td>Hispanic</td>
</tr>
<tr>
<td>David</td>
<td>5.3</td>
<td>5.6</td>
<td>Male</td>
<td>Latino</td>
</tr>
<tr>
<td>Jay</td>
<td>5.3</td>
<td>5.6</td>
<td>Male</td>
<td>Hispanic/Asian</td>
</tr>
<tr>
<td>Mike</td>
<td>4.9</td>
<td>5.0</td>
<td>Male</td>
<td>African American</td>
</tr>
<tr>
<td>Ann</td>
<td>4.9</td>
<td>5.0</td>
<td>Female</td>
<td>Hispanic</td>
</tr>
<tr>
<td>Dana</td>
<td>4.5</td>
<td>4.8</td>
<td>Female</td>
<td>Hispanic</td>
</tr>
</tbody>
</table>

**Maximal Variation Sampling**  One feature of qualitative research is offering multiple viewpoints to reflect the complexity of individual experience in the real world. Maximal variation sampling is a method that allows for purposeful participant selection who differ on some unique feature. In this type of sampling, the researcher identifies the characteristic and then finds individuals who possess this trait (Creswell, 2002). In this study, the researcher identified preschoolers’ mathematics ability by giving an assessment to purposefully select six participants, two at each level: lower, middle, and high mathematics abilities. Students were then purposefully selected by their prior experience with technology at two levels: novice and experienced, as reported by the parental questionnaire, teachers, and researcher’s observations. Table 2 shows
the matrix that depicts the relevant criteria for purposeful participant selection according to mathematics and technological abilities.

**Table 2 - Matrix Depiction of Relevant Criteria for Purposeful Selection**

<table>
<thead>
<tr>
<th>Novice Technology Usage</th>
<th>Experienced Technology Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Mathematics Ability (1) Dana</td>
<td>Low Mathematics Ability (1) Ann</td>
</tr>
<tr>
<td>Novice Technology Usage</td>
<td>Experienced Technology Usage</td>
</tr>
<tr>
<td>Average Mathematics Ability (1) Chase</td>
<td>Average Mathematics Ability (1) David</td>
</tr>
<tr>
<td>Novice Technology Usage</td>
<td>Experienced Technology Usage</td>
</tr>
<tr>
<td>High Mathematics Ability (0) no-one</td>
<td>High Mathematics Ability (2) Jay/Mike</td>
</tr>
</tbody>
</table>

**Parents.** Parents or legal guardians of the participating students completed questionnaires to collect data concerning students’ gender, ethnicity, age and outside use of iPads and other technological applications. This information is valuable because it can serve as a foundation for more fully understanding the participants’ home environments and preexisting knowledge of technology.

Justification of Length

For this qualitative research using a case study design, iPad implementation occurred over a fourteen-week period. For this design, the researcher was most influenced by her previous work in studying preschoolers and iPad implementation; two earlier studies investigated preschoolers’ interactions with the Math Shelf curriculum. One of these studies implemented iPad play for thirty minutes a week over the course of six weeks; this was a successful model for this research because student engagement remained high (Schacter et al., 2016). The second of these studies occurred over a fifteen-week period, wherein the researcher played the role of research assistant; ultimately, the researcher found this timeline less effective as a model because
student engagement faltered by the study’s end. This could be due to the fact the students only played one math app, which may have bred boredom (Schacter & Jo, 2016). Related research investigating similar phenomena (technology integration in the classroom) or subject matter (number sense) among similar populations (preschool or elementary-aged children) has varied in its implementation period. Cohen, Hadley, & Frank, (2011) observed sixty 2- to 8-year-old student interactions with iPads over an eight-week period. Furthermore, Lee (2015) utilized a Case study design over a fifteen-week period to work with 3- to 5-year-old low-income preschoolers and study how learning can be fostered by digital devices. Finally, a study focused specifically on constructivism in mobile learning observed first graders for four weeks with sessions ranging from ten to twenty-five minutes for twenty sessions total (Zurota & Nussbaum, 2004). Ultimately, the researcher selected a fourteen-week implementation period based on her previous research experiences and these models.

Research Schedule

This section briefly discusses the research schedule and iPad apps were played during the iPad sessions.

Week 1: Parental signatures were gathered, and parents took the questionnaires. Parent questionnaires, available in Appendix D, were collected. Parent questionnaires defined students’ technology experience and skill outside of the classroom and were used in the purposeful selection of participants at various technological ability levels, categorized as novice or experienced. The TEMA test was given, collected, and analyzed for purposeful participant selection; a full selection of age-appropriate TEMA prompts is provided in Appendix A. The TEMA additionally served as an instrument to purposefully select students at various levels of mathematics ability.
Week 2 day 1: Students completed the Student Activity Worksheet as an additional introduction to their number sense knowledge. This served as a more practical source of contextual information about student skills; a complete Student Activity Worksheet is provided in Appendix E. After Student Activity Worksheet was completed, the researcher provided brief overview of iPad functionality and apps. Students then played with the first iPad app for 10 minutes. During routine iPad app sessions, the researcher used the observation protocol, available in Appendix B, as a rubric for observing participant interactions specifically with the number sense content of apps. The observation protocol was utilized during every app session for the study’s duration.

Week 2 day 2: Students were introduced to the second iPad app and played individually for 10 minutes.

Week 2 day 3: Students were introduced to the third iPad app and played individually for 10 minutes. The fourth app did not need an introduction, ST Math, because it was routinely used in participants’ classrooms.

Weeks 3-14: This pattern was continued for the study’s duration: preschoolers interacted with four different apps each week for ten or more-minute sessions for a duration of fourteen weeks. In total, each child was observed by the researcher approximately 21 hours over the duration of the fourteen weeks. Videotapes ranged between 3-7 hours for each student and captured interaction with the apps. All sessions were documented via real-time video capturing students’ screens and touch counts to observe their iPad interactions. These tapes captured affordances and constraints accessed by students. During this time, the researcher observed students’ behaviors in regular mathematics classroom activities to note student, teacher, and, if available, iPad interactions. Additionally, the researcher collected vital artifacts, field notes, and
documentation to gain a more intimate and holistic understanding of each student’s relationship with mathematics and possibly classroom technology, if utilized. The frequency and duration of these classroom visits were determined in part by teacher approval and classroom schedule but occurred three times a week.

Week 13 day 1: The researcher concluded interviews with preschoolers to accompany initial interviews and further illuminate children’s experiences with iPad technology over the course of the study. A list of semi-structured interview questions for the preschoolers are available in Appendix F. The researcher also interviewed teachers and teachers’ aides; interview questions are available in Appendix G.

Week 13 day 1: A second assessment was given to capture the nature of the change of participants’ number sense knowledge. The researcher concluded with a second assessment via the Post-TEMA.

Week 13 day 2: Students completed the Post-Student Activity Worksheet as a second assessment to their number sense knowledge.

Week 14: Researcher interviewed classroom teachers and teacher’s aides. The researcher also reserved this week to collect any loose ends.

Research Content

These four apps were selected among eight reviewed. In the event one of these apps undergoes a significant design or content revision due the rapid production and development of technology, the researcher has included in Appendix H the other reviewed apps as potential substitutes.

**Description of ST Math** The ST Math comprehensive math curriculum was developed by the MIND Research Institute (MIND Research Institute, 2018). It was created to teach
mathematical concepts through spatial temporal representation. Spatial temporal representation is an intuitive skill that involves visualizing and maneuvering images through systematic steps, which are necessary to answer questions in mathematics and other disciplines (MIND Research Institute, 2018). Spatial temporal mathematics uses animated pictures to aid students in developing spatial temporal thinking, which leads to a more profound understanding of mathematical concepts (Tran et al., 2012). In this study, concepts of counting and cardinality, operations and algebraic thinking, number and operations in base ten, geometry, and measurement and data were explored by preschoolers. In the mathematics software program, students play with visual math games developed to teach math concepts. The program is designed for use from preschool through fifth grade (Schenke, Rutherford, & Farkas, 2014). The interactive interface of the software offers individualized instruction and matches student needs for learning. It allows students to progress at their own pace (Rutherford et al., 2014). The game-like exercises are simple in the beginning and gradually become more challenging as the student successfully works through modules. Linear game play permits students to progress to a more difficult level only after the current level has been mastered. The level must be finished before making two mistakes with an 80% success rate or they must repeat the level (Rutherford et al., 2014).

The digital game-like mathematics puzzles are created to help preschoolers explore and investigate foundational number sense and early mathematics skills. The program fosters student learning experiences by allowing them opportunities to think critically and develop problem-solving skills. The mascot of the app is JiJi. JiJi is an animated penguin that crosses the screen from left to right when students demonstrate knowledge correctly on a mathematical objective (Bjerede, 2014). The game’s elements are mathematics: to move JiJi to the next level or module,
students must overcome obstacles in JiJi’s pathway by resolving more difficult mathematics tasks. The puzzles and games within the modules create a bridge for young students to learn mathematics. As the students solve the puzzles, they are given constant instructional feedback to aid in further progress. The students will often associate getting JiJi to the next level with a thrill of success (MIND Research Institute, 2018). JiJi and the interactive virtual manipulatives help motivate students to study and connect mathematical concepts.

Due to the fact that mathematical concepts are displayed through storybook-like images, children of any culture could find ST Math beneficial. The barrier of language is eliminated for English language learners, so students do not have to master math and language obstacles simultaneously. Most concepts are explained first in a language-free manner, then students are gradually exposed to language and mathematical symbols. This was ideal for the research setting since the school served mostly Hispanic students who had language barriers in communication. By delivering mathematics concepts with dynamic representations conveyed by visual animated image-based instruction, ST Math is hypothesized to benefit ELL students’ mathematical academic outcomes (Ruterdorf et al., 2014).

Computer-based instruction promotes a positive effect on student learning (Tran et al, 2012). Other studies in mathematics have indicated that video-based instruction is positively correlated to student mathematical understanding (Shyu, 1999). Additionally, relationships between spatial representation and understanding quantity without symbol representation is a successful avenue to improve student learning of mathematical concepts (Geary 1995,). Visual representations can bridge the gap of understanding for preschool children and provide opportunities to connect numerical symbols and representations, thus enhancing understanding.
When students can connect visual images to mathematics procedures such as addition and subtraction, favorable outcomes are achieved.

The ST Math’s software can be accessed through an app platform, allowing students to access mathematical instruction from both school and home. The app provides portability and flexibility for students’ educational needs and experiences. It is ideal for students who might be struggling with mathematical concepts and need extra practice to gain mastery of early number sense objectives (Website STMath). ST Math instruction has been linked to improved scores on standardized tests (Bjerede, 2014).

More interaction with ST Math was observed in this research because it was an implemented part of the preschool classroom curriculum. Mrs. Newman’s preschoolers used the ST Math program for 30 minutes a day and Mrs. Day used ST Math approximately 15 minutes a day. Below are the objectives assigned on the ST Math software in the classrooms.

**Assigned objectives and optional objectives on ST Math.**

Assigned Objectives

Domain - Counting and Cardinality

- Number and Objects to 5
- Subitizing
- Numbers and Objects to 10
- Greater Than, Less Than, Equal to
- Numbers and Objects to 20
- Comparing Numbers

Domain – Operations and Algebraic Thinking

- Understanding addition and subtraction within 5
• Understanding addition and subtraction within 10
• Making 10 and number pairs
• Addition and subtraction facts within 5
• Challenge

Domain - Geometry
• Exploring shapes
• Analyzing shapes
• Composing shapes
• Position LI

Domain – Number and Operations in Base Ten
• Introduction to the numbers
• Number and Counting to 100
• Foundations of Place Value

Domain – Measurement and Data
• Sorting and Classifying
• Measurable Attributes
• Reasoning and Attributes

Optional Objectives
• Exploring Patterns
• Advanced Patterns
• Technology Interaction
• Position
• Concepts of Time
**Montessori Numbers.** This app provided an assortment of activities to practice number concepts. Activities such as counting, dragging blocks to match given numbers, ordering number symbols 1 through 9, identifying numbers, matching quantity to number symbol, and tracing numbers are incorporated into this app. A nice component of this app has the ability to set the difficulty of mathematical content by selecting the range of numbers to be practiced. For example, a student could work on numbers 1 to 3, 1 to 5, or 1 to any selected number range.

**Math Shelf.** Mathematics Shelf is an app developed on research principles surrounding mathematics skills and mathematics sequences; it incorporates a variety of Montessori’s physical manipulatives in a digital format. These manipulatives include colorful beads, subitizing cards with number representation, counting chips, and numbered rods. It has a progression of sub-apps that address important competencies such as “subitizing, ordering quantities, one-to-one counting, and matching different quantity representations” (Schacter, Shih, Allen, DeVaul, Adkins, Ito, 2016). Mathematics Shelf has a variety of sub-apps; this study included only the following sub-apps: pink tower, 1 to 3, 1 to 5, 1 to 9, bead addition, dice addition, number addition, charts 20, and addition to 10. Mathematics Shelf has undergone significant design changes, but these sub-apps are still offered in the trial version. This research is only interested in certain tasks from these apps.

**Elmo Loves 123.** The app consists of all the familiar characters on Sesame Street. This app provides games, puzzles, songs, activities, and videos for children to learn numbers from 1 to 20. Children get to explore numbers with Elmo in interactive tasks such as trace the number, a digital display coloring book, and hide and seek number games. The app can support children in learning about number identification, number symbols, counting groups, problem-solving, and creativity. It was developed by Sesame Street Workshop apps incorporated.
**ToDo Mathematics.** This app provides animated personal learning tasks for children through fun and colorful digital world. For example, there is a section called little farm wherein the child matches different animal figures to representations on a card. The app provides matching tasks, in which symbols of numbers are matched to representation numbers 1 to 20. ToDo Mathematica’s activities involves basic mathematics concepts such as counting and cardinality, number operation, mathematic reasoning, time, money, and geometry. Parents and teachers can monitor user’s progression.

App Selection

When considering this research project, one must decide how the iPad apps will be selected. Although digital platforms have been depicted as transformative in the learning process, very few guidelines for teachers on how to choose apps have been explored. Cayton-Hodges, Feng, & Pan (2015) recently mentioned there are four important areas to review when analyzing the quality of mathematics apps: content, scaffolding and feedback, interactivity, and adaptability. MathApps (2015) also included the following categories when developing their MathApps analysis website: level of cognitive demand, content standards, and standards for mathematical practice, which could be helpful when thinking about important characteristics of iPad apps to employ with students in an educational setting.

When selecting apps for this project, particular attention was given to the level of cognitive demand for apps. The apps were evaluated according to: low cognitive demand tasks (memorization and procedures without connection) and high cognitive demand tasks (procedures with connection and doing mathematics). Memorization in apps generally entails the reproduction of already-learned processes, definitions, or facts. Procedures are not used or called for in these tasks. Procedures without connections in apps implicitly or explicitly call for
particular procedures or algorithms without any apparent connection to underlying concepts. Procedures with connections in apps implicitly or explicitly call for particular procedures or algorithms but do so to make connections to underlying concepts. When doing mathematics, which has high cognitive demand, apps require users to demonstrate, in some form, investigation of complex relationships and related concepts. Completion often requires problem-solving, reflection, creating algorithms, generalizations, and/or conjectures (MathApps, 2015; Stein & Smith, 1998).

Other criteria for selecting apps was the quality of mathematics content, engagement, feedback and scaffolding, differentiation, and ease of use. The apps needed to cover mathematical content that was significant for the learning of number sense such as recognizing small numbers, subitizing, ordering, enumerating objects (connecting the number words with objects), and supporting the child in recognizing that the final numeral articulated corresponds to the total number of items counted (Clements & Sarama, 2014). When considering the mathematical content in an app, the mathematics concepts need to be handled in an appropriate way and should build on prior knowledge. Engagement characteristics of the apps should greatly motivate students to use the app (Vincent, 2012). The feedback and scaffolding aspects of the apps are also important because students often use apps without the supervision of teachers. Apps’ feedback should assist in redirecting students towards a correct answer. Apps that provide similar questions to those missed, simplify a skill, or provide clues to help students improve their performance can be beneficial in mobile learning. Significant to the feedback and scaffolding characteristic of an app can be the teacher’s ability to view students’ work later for direction or redirection of instruction (Walker, 2011). Differentiation in an app is vital to individual student instruction; being able to select level of difficulty or target precise skills can increase the
possibility of student success (Walker, 2011). Differentiation features need to be easy-to-use and appropriate for diverse student needs (Vincent, 2012). “Easy-to-use” refers to the child’s ability to launch and independently utilize the app (Vincent, 2012). Dynamic factors that can affect this aspect of ease of use are having directions read aloud, step-by-step sequential color code mathematics instruction, and student control, allowing students to move between levels of difficulty (Walker, 2011). The rubric used to evaluate apps is included below. It is modified from a rubric created by Harry Walker from Johns Hopkins University in 2010. The original rubric has authenticity as a category, but since this study is not interested in authenticity, the category was removed. Rubrics for each of the eight apps reviewed for this study can be found in Appendices I-P. The apps have been reviewed by three to four researchers for various national mathematical conferences presentations. See Table 3 for the rubric used to evaluate the apps.
### Table 3 - Evaluation Rubric for Apps.

<table>
<thead>
<tr>
<th>Domain</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cognitive Demand</strong></td>
<td>Tasks in app require user to demonstrate, in some form,</td>
<td>Task in app implicitly or explicitly call for particular</td>
<td>Task in app implicitly or explicitly call for particular</td>
<td>Task in app generally involve reproducing previously learned</td>
</tr>
<tr>
<td>(Adapted from MathApps 2015)</td>
<td>investigation of complex relationships and relate concepts.</td>
<td>procedures or algorithms but do so to make connections to</td>
<td>procedures or algorithms without any apparent connection to</td>
<td>rules, formulas definition, or facts. Procedures cannot/ are</td>
</tr>
<tr>
<td></td>
<td>Completion of requires problem-solving, reflection, creating</td>
<td>underlying concepts.</td>
<td>underlying concepts.</td>
<td>not used or called for in the tasks.</td>
</tr>
<tr>
<td></td>
<td>algorithms, generalizations, and/or conjectures.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mathematics Content</strong></td>
<td>The content in the apps is handled appropriately and builds on</td>
<td>The mathematics content in the app is correct but the app does</td>
<td>The mathematics in the app has a few errors and does not build</td>
<td>The mathematics in the app is incorrect and does not represent</td>
</tr>
<tr>
<td></td>
<td>prior knowledge.</td>
<td>not build on prior knowledge.</td>
<td>build on prior knowledge.</td>
<td>best practices.</td>
</tr>
<tr>
<td><strong>Engagement</strong></td>
<td>The student is highly driven to interact with the app.</td>
<td>The student interacts with the app when directed by a teacher.</td>
<td>Student perceives the app as work and may stray from the task</td>
<td>Student does not want to use the app and may gripe when it is</td>
</tr>
<tr>
<td>(Vincent, 2012)</td>
<td></td>
<td></td>
<td>when using the app.</td>
<td>required.</td>
</tr>
<tr>
<td><strong>Feedback and Scaffolding</strong></td>
<td>Student is provided with specific feedback and lessons are</td>
<td>Student is provided with general feedback. Exporting the student</td>
<td>Student is provided limited feedback. Limited assessment data or</td>
<td>Student is provided with no feedback. No performance summary or</td>
</tr>
<tr>
<td>(Vincent, 2012)</td>
<td>scaffolder appropriately. Teacher can also view students’ work</td>
<td>feedback is difficult or limited.</td>
<td>no accessible student product.</td>
<td>product is saved.</td>
</tr>
<tr>
<td></td>
<td>at a later date.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Differentiation</strong></td>
<td>The app can easily be altered to meet the needs of diverse</td>
<td>The app offers more than one degree of flexibility to meet</td>
<td>The app offers limited flexibility (few levels).</td>
<td>The app offers no flexibility and settings can’t be altered.</td>
</tr>
<tr>
<td>(Vincent, 2012)</td>
<td>learners.</td>
<td>students’ needs.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Use</td>
<td>Student is able to launch and independently use the app.</td>
<td>Students needs teacher assistance to launch and use the app.</td>
<td>Student needs teacher cues when the app is open.</td>
<td>App is challenging to use or frequently shuts down.</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------------</td>
<td>---------------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
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</tbody>
</table>

Description of Instruments Used for Purposeful Sampling

**Instruments of the TEMA.** The TEMA is an assessment that identifies young learners’ capabilities in early mathematical knowledge. For this research, the TEMA was used to document the children’s mathematics skills for purposeful selection; it furthermore illuminated the nature of the change in student knowledge by being utilized at the study’s conclusion as a second assessment. To condense testing time, each child’s entry point, ceiling (knowledge cap), and basal (lower knowledge boundary) is used. The administrator started the test using entry points of the child's age which were correlated to questions on the TEMA. Students reach a ceiling of mathematics ability when they answer five consecutive questions incorrectly. Once a ceiling has been determined, a basal must be determined. Students reach a basal when they answer five consecutive questions correctly.

**Reliability.** TEMA reliability data ensures that the test results are accurate and accurately measure, in this case, mathematics ability. Using the Cronbach’s method (1951), the coefficient alpha was determined on the TEMA for six age groups of children ranging from three to eight years of age. All the coefficient alphas calculated indicated that the TEMA is a highly reliable test, spanning from .92 to .96. Also, reported on the TEMA was a test-retest coefficient, which indicates the extent to which students’ test scores remain constant over a period of time. Test-retest correlation coefficients were given on the different forms of the test and were found to be .82 and .93. Additionally, an alternate forms immediate administration method was employed on the TEMA. For TEMA, six different age groups’ scores were correlated between form A and
form B. A reported coefficient of .97 provides further confidence in TEMA test scores to be reliable with little content sample error (Ginsburg & Baroody, 1990).

**Validity.** In the first of three content-description validities of the TEMA, conventional item analysis was reported, which looked at the test item’s difficulty and item’s discriminating power. The item-total-score Pearson correlation index was used to select test questions, which all met criteria standards. A differential item functioning analysis was also preformed, in which questions were evaluated to remove any biases or questions that promote stereotypes, including ethnocentric or gender-established assumptions that may offend the examinee (Ramsey, 1993). For evaluation of the criterion-prediction, scores were correlated with other tests that measure early mathematics skills. The mathematics sections of the KeyMath-R/NU, Woodcock Johnson III Test of Achievement, Diagnostic Achievement Battery-Third Edition, and the Young Children’s Achievement tests were used in comparison to the TEMA scores. These coefficients show a highly significant correlation between the TEMA’s mathematics ability score and scores on the above tests ranging from moderate to very high, indicating the TEMA possesses criterion-prediction validity (Ginsburg & Baroody, 1990).

**Student Activity Worksheet**

The students also completed the Student Activity Worksheet, which was series of administered questions via worksheets that allowed the researcher to gain insight and descriptions about the preschoolers’ mathematics ability. Students were asked to perform tasks such as the following: identifying numbers, counting beads of different quantities, naming and comparing numbers, matching counting beads to correct number symbols, and identifying the missing number. The complete Student Activity Worksheet can be found in Appendix E. This assessment had been used in trial research projects leading up to this study under the direction of
Data Collection

Important materials to collect for a case study are interviews, observations, documents, and artifacts (Yin, 2014; Marshall & Rossman, 2011; Creswell, 2013). This section covers the necessary materials for the research study and semi-structured preschooler interviews, videotaping procedures for observation, observation protocol, parent questionnaires, and artifacts to be collected. See Figure 1 for illustration of data collection.
Materials Needed for this Research

5-7 iPads—The researcher provided 2 iPad for this study; additionally, 5 iPads were used from the teachers’ classrooms.

Access to 4-5 mathematics-based apps—ST Math, ToDo, Montessori Numbers, Elmo Loves 123, and Mathematics Shelf were loaded onto 5-7 iPads

2 GoPro cameras—To capture the students playing with iPads, the GoPros was used. A GoPro camera is a small, portable camera that can be attached to almost anything. The GoPro allowed the researcher to tape students without invading their learning environment.

AirServer Connect—This is an app that is useful for educational environments with more complex network systems. This program was used to connect the iPads to the researcher’s computer so that sessions could be recorded and retrieved later for analysis.

Test of Early Mathematics Ability (TEMA)—The TEMA testing kit consisted of an examiner’s manual, assessment probes and instruction booklet, 50 examiner record sheets (25 of form A and 25 of form B), 5 x 8 cards, 25 block manipulatives, 25 token manipulatives, and a tote bag. The kit can be purchased for $321.00 (Ginsburg, & Baroody, 1990).

Student Activity Worksheet Appendix E

Questionnaires for parents are provided in Appendix D.

Semi-structured questions for children interviews are provided in Appendix F.

Semi-structured questions for teachers’ interviews are provided in Appendix G.

The observation protocol for iPad Interactions is provided in Appendix B.

A document for the collection of field notes and artifacts is provided in Appendix Q.

An audio recorder was used to record interviews.
Data Collection Procedures

**Parent questionnaires.** Parents were asked to complete a questionnaire to gain more insight on children’s use of technology outside of school. Parents were asked questions such as:

What activities does your child do on the iPad? Select all that apply.

- _____ Take pictures/selfies (1)
- _____ Listen to music (2)
- _____ Watch educational cartoons or videos (3)
- _____ Watch entertainment cartoons or videos (4)
- _____ Play entertainment games (5)
- _____ Play educational games (6)
- _____ Communicate with family or friends via Skype, FaceTime, phone calls, etc. (7)

Some questions followed a response format of No Opinion (1), Strongly Disagree (2), Disagree (3), Agree (4), and Strongly Agree (5).

The completed parent questionnaire is located in Appendix D. It was developed by using Qualtrics and combining several already-developed surveys and modifying them to allow collection of information on young children’s technology use outside of school. Some questions are modified from mathematics survey questions from Schmidt, Baran, Thompson, Mishra, Koehler, and Shin (2009a). All the questions pertaining to mathematics and iPad use are from this article. Other questions came from research by Chiong and Shuler (2010). Additionally, questions came from South Central Schools’ *Technology Survey for Parents*. The questionnaire captured details surrounding children’s experience with technology at home. For example, one child I previously worked with played with the iPad all the time at home and, therefore, while at
school did not always have interest in play, but other participants without home access mostly had higher engagement with the iPad. Thus, preschoolers who did not have home access to the iPad were more willing to play with the iPad apps in the classroom setting.

**Semi-structured interviews.** Young children were interviewed about their experiences with the iPad apps. Students were asked what they like or dislike about the apps. Teachers and teachers’ aides were also interviewed to gain vital information about iPad implementation and student descriptors. Semi-structured interviews can be a useful resource for gathering data from children (Bernard & Ryan, 2010), and further provide detailed descriptions that generate a great deal of qualitative data (Creswell, 2013; Marshall & Rossman, 2011). The semi-structured interviews were audio taped and occurred in the later weeks of the research after the children had a chance to play the different iPad apps. Here are a few examples of the children’s interview questions: *Do you like playing with the iPad? What do you like about it? What do you dislike about it? What was your favorite mathematics app that you played with during your iPad sessions here at school?* Some of these questions were modified from Ditzler, Hong, and Strudler’s research (2016). A complete list of semi-structured interview questions for students can be found in Appendix F. A complete list of semi-structured interview questions for the teachers can be found in Appendix G.

**Observation procedures for video recordings.** Students were documented in real time two different ways. The first involves an external camera, the GoPro. Students worked individually with the iPad playing number concept apps in three ten or more-minute sessions, totaling thirty plus minutes each week for fourteen consecutive weeks. Videos were taken of the students’ interactions with the iPads during these fourteen weeks. Video recordings focused on the interactions between the students and the iPad apps. Video helped illustrate how children
interact and play with number sense apps in a one-to-one setting. According to Plowman and Stephen (2008), videos can make possible documentation of complex interactions with technology and preschoolers. While video is not conducive to directly identifying learning, it without a doubt emphasizes language, hand gestures, touches, eye movement, and physical action. When used with contextual data, researchers can make judgements about children’s experiences and learning. Researches consistently rely upon videos to make available recording of young children in preschool sites (Plowman, Stephen & McPake, 2010).

Additionally, videos documented children’s interactions with the different learning performance tasks, such as moving rods from largest to smallest, ordering numbers correctly, and matching numbers to representations. The videos further documented the learning progress of these tasks and recorded time of task completion; additionally, videos captured affordances and constraints accessed by the students. The videos’ focus was on preschoolers’ hand movements with the iPad’s touchscreen interface. The videos captured only the child's hand movement and the iPad, avoiding students’ faces to help with IRB regulations. The GoPro and iPad camera recorded interactions that occur between the iPad and the students and any conversations that may occur during the iPad sessions.

The second method of video documentation for recording student interactions involved internal real-time mirror-imaging via AirServer Connect. The AirServer Connect app simultaneously recorded and streams the child’s actions within the apps to the researcher’s hard drive. This allowed for nonintrusive observation of children’s organic activities and future viewings of the documented interactions. According to DeCuir-Gunby, Marshall, and McCulloch (2012), video data can be extremely fitting for evaluating preschoolers’ interactions since it permits multiple viewings. The mirror image videos can be viewed as many times as necessary
to focus on different aspects and make new insights with each viewing. It can also be a resource for future research.

**Observation protocol.** An observation protocol was used to collect details regarding preschoolers’ interactions with the number sense iPad apps. The complete observation protocol can be found in Appendix B. This protocol provides the researcher an organized way of recording important iPad session information, ultimately to capture students’ progression of learning with number through the duration of the study. This document was created to allow the researcher to record information, denote detailed descriptions, and write reflective notes about the iPad sessions. The protocol was allowed collection of notes, the researcher’s experiences, and hunches (Creswell, 2007). It was also allowed the researcher to collect measurements of interactions associated with learning number sense. Additionally, the observation protocol is a place to note certain tasks within the mathematics apps.

It additionally housed observational field notes regarding students’ perceived engagement, mood, affordances or constraints accessed, and ability to navigate the device. The following interactions with the mathematics-based apps were measured to ultimately describe children’s processes and abilities to learn through activity: ability to correctly identify numbers, match quantities to numerals, and order numbers 1-10 correctly. The observation protocol further measured students correct and incorrect answers as well their interactions with the apps’ scaffolding and signifiers.

**Field notes and artifacts.** Field notes and artifacts were gathered when the researcher directly observed the preschoolers in their regular classroom mathematics activities. During this observation, the researcher took field notes about each child and their participation in the mathematics lessons as well as their technology usage if applicable. The researcher collected
artifacts, including mathematics lessons and copies of preschoolers’ completed work, to provide a holistic illustration of each student within the study. Furthermore, pictures were taken of student work, student activities, and interactive play at preschool leaning centers.

Data Analysis

Multiple data sources such as semi-structured interviews, observations, and questionnaires were collected to triangulate the findings and provide a robust data context (Creswell, 2013; Maxwell, 2013). Data comes in a several forms within this study such as interviews, field notes, observational documents, artifacts, photographs, and videos. Yin (2014) defined triangulation as the merging of different data sources to show consistency of the results. Furthermore, significant data could be obtained through observation and detailed descriptions via videotaping or transcribing specific behaviors that could be observed (Maxwell, 2013). In this research, information from the semi-structured interviews, parent questionnaires, field notes, and video-taping was merged to provide details about iPad usage and students’ interactions. A combination of attribute, in Vivo, and narrative coding were used in this case study, which is appropriate according to Saldana (2016).

Coding was also used in this qualitative case study by two research coders to analyze the data collected. As is typical, these codes consisted of a word or brief phrase that metaphorically assigned a collective, significant, essence-capturing, and/or suggestive characteristic to a fraction of language centered on visual or transcribed information (Saldana, 2016). Coding permits data collected to be transitioned into additional data analysis. The process of coding allows data to be separated, arranged, rearranged, and relinked with the intention of meaning and clarification (Grbich, 2007).
Inductive methods of analysis were employed with the collected qualitative data (Bernard & Ryan, 2010; Creswell, 2007). Data analysis worked to build a thorough description of the case. This section covers how raw data from parent questionnaires, semi-structured interviews, video recordings of student interactions with the apps, and field notes and artifacts was additionally analyzed.

**Analysis of parent questionnaires.** The main aim of the parent questionnaires was to contextualize the preschoolers’ usage of technologies in the home setting and gain insight to parents’ perspectives on participants’ interplay with iPad number sense apps. Additionally, the parent questionnaires provided age, gender, and ethnicity information about the students. Parental insight provided the researcher with a holistic description of children’s technological experiences. This data was used for purposeful selection and analyzed to detect emerging patterns related to individual participants’ preexisting knowledge of technology. The parent questionnaires’ results and accompanying data were first analyzed, then visualized through tables (Wolcott, 1994b). Attribute coding was used with the parent questionnaires and other field note documents due to the fact that they provided essential participant information. This information included age, grade level, academic status, gender, ethnicity, social class, data collection format, date, and time frame (Bazeley, 2003; DeWalt & DeWalt, 2011; Gibbs, 2002; Loftland et al., 2006).

**Analysis of semi-structured interviews.** The semi-structured interviews with preschoolers and teachers were transcribed verbatim to produce rich data (Maxwell, 2013). There was a total of 17 semi-structured interviews collected in this research study. Both the main teachers, Miss Day and Miss Newman, and both of their teachers’ aides and thirteen students were interviewed. After the interviews were transcribed, the text was coded; an example of the
coded interviews can be found in Appendix R. These codes from the interviews helped form the research’s areas of interest, such as benefits of the iPad, usage of the iPad, engagement with number sense apps, participants’ basic descriptors, participants’ academic descriptors, and participants’ technology skills and attitudes toward technology. Student interviews, videotapes, artifacts and field notes further revealed a high level of enjoyment and motivational engagement when acquiring number concepts in a game-based framework.

Data analysis of these interviews entailed two-rounds of the coding process (Saldana, 2009). In the first round of coding, two researchers used open coding of the interview transcriptions. This allowed researchers to see emerging descriptors in relation to students’ experiences with mathematics concept apps. To confirm credibility of the analysis, researchers came together and discussed each coded interview to compare codes.

These codes were then used to write narratives about preschoolers’ perspectives, usage, and experiences around iPad play. The teacher interviews included descriptions about how the iPad and apps were used in the classroom. Each student’s personality, academic level, progress in math ability, and some technological descriptors were provided by teachers. Narratives of teacher interviews were shared with participating teachers for member checking. These narratives constructed descriptions of each case. In Vivo coding was employed here to capture short phrases or terms within the actual language found in the semi-structured interview portions of the qualitative data. These phrases were words spoken and expressed by teachers and students. This type of coding was the primary coding method used for the semi-structured interviews. However, some exact phrases expressed by students during inactive play were captured on video and denoted in quotation marks in the data analysis and results sections (Charmaz, 2006; Corbin & Strauss, 2008).
Analysis of video recording. The video recordings and observation protocol also provided data that was mined for patterns or themes (Miles & Huberman, 1994). A comprehensive analysis of video recordings from this study revealed observational behaviors of the preschoolers’ interactions with the number sense game-based apps. Affordances and constraints were identified by watching repeated viewings of the videos. Figure 7 depicts the research flow from raw data, to narrative logs, to codes, to categories, to patterns, and then to themes and concepts.

Figure 7 - Research flow, adapted from Saldana (2016).

Narrative logs and codes. Narrative logs were produced to depict the students’ observable interactions with the affordances and constraints captured via the videos (Moyer-Packenham, 2015). Examples of the narrative logs can be found in Appendix S. These narrative logs described the number sense tasks and the students’ corresponding interactions. Then, the narrative logs enabled researchers to shrink the data into short codes of recurring patterns of action. Narrative coding was employed to create story-like literature elements to depict each
purposefully-selected participant’s interactions with the game-based apps. Then, codes were formed to describe the students’ educational experiences from the narrative logs (Saldana, 2016). The researcher’s codebook can be found in Appendix C. The codebook contains an inventory of codes culled from analysis of videotapes of the students’ interactions with the number sense apps.

**Categories.** Six main categories emerged from the codes; these were: scenario, affordances, grouping of 10, progress-based path, concrete manipulatives and collaboration. The affordance category had several subcategories which included immediate feedback, verbal pronunciation, quantity to written symbol, and visualization of touch counts. The first four of the categories – scenario, affordance, grouping of 10, and progress-based path – are attributes that occur internally, or within the app’s design, context, and content. The last two categories – concrete manipulatives and collaboration – illustrate the external elements of how children play with iPads. Diagram X illustrates the main categories found in this study. Categories are the foundations of qualitative research; they describe characteristics of the phenomenon in question (Strauss & Corbin Need Year): in this case, preschoolers playing with iPad-based number sense apps. Figure 8 provides the categories which emerged from this research’s data.
Patterns. From the categories, patterns surfaced. Patterns are repetitive or consistent events of action within the data. Patterns happen greater than twice in the data. Patterns can include similarity, difference, frequency, and correspondence characteristics (Saladana, 2016).

Scenarios. In the category of scenarios, two patterns appeared. Preschoolers who could comprehend the game-based scenarios correctly using problem-solving skills and accurately responded to number sense tasks did not have to repeat the level and moved to the next level. Preschoolers who could not understand the scenario and who could not master the number sense tasks had to repeat the levels.

Affordances. In the immediate feedback subcategory, one overall pattern observed was that immediate feedback allowed all students to recognize their mistakes. Two additional patterns were observed: lower performing students who had to repeat the levels utilized the immediate feedback to empower themselves to self-correct their mistakes. However, the higher
performing students who did not repeat levels focused on immediate feedback that validated their reasoning as they advanced to the next levels. Immediate feedback for the higher preschoolers became a mark of how many questions they could get right or wrong to advance to the next level.

In the verbal pronunciation subcategory, one main theme emerged. If a preschooler could not order or identify numbers correctly, an audio voice aided the student in correctly answering questions. This affordance of verbal pronunciation allowed students at all levels to more accurately engage with the mathematics content.

In the subcategory of quantity to written symbol, the pattern that emerged was that all students used this affordance when learning numbers 1-20. The iPad app created varied tasks wherein written symbol and visual representation were consistently and repetitively presented in the curriculum. This consistency and repetition allowed students to connect these two concepts.

In the subcategory of visualization of touch counts, the consistent pattern was that students used the iPad’s touch counts to practice counting. Consistently and repetitively, ordering and counting quantity involved a physical, tangible touch that was usually accompanied by a visual response from the virtual manipulatives onscreen. This multimodal, sensory element of the iPad apps helped all participants at all levels in learning numbers. Observation via video recording and field notes revealed that this affordance was the most frequently utilized by participants.

**Grouping of Ten.** In the category of grouping of ten, two regular patterns revealed themselves. Lower performing students who did not transition into grouping 10 units of ones into a set group of ten had to constantly count each block to identify numbers 11-20. When counting any number higher than 10, these participants had to count each and every object onscreen in a
one-to-one manner of correspondence. This repetitive manner of one-to-one correspondence counting became tedious and inefficient to participants, eventually decreasing participant engagement with the game’s content. Higher performing students who did transition into grouping an unchanging set of 10 were faster to identify a set of ten and did not need to count with one-to-one correspondence. These students progressed much more quickly and efficiently when learning two digit numbers.

**Progress-Based Path.** In the progress-based path category, a pattern involving a motivational aspect emerged. This motivational aspect of ST Math was encapsulated in students’ expression of enthusiasm to advance JiJi to the next level. In ToDo Math, there was a CandyLand-esque progressive path that led to the next level. Students would often say “Next level, next level!,” “Go JiJi!,” “JiJi next level!,” and “Moving on!” to voice achievement.

In the concrete manipulative category, the pattern that occurred was the need for lower number sense students to use counters, cards, and charts to correctly answer questions and complete tasks on the number sense iPad apps’ games. This pattern was most often seen with students who exhibited lower number knowledge. These participants required something other than or additional to the virtual affordances offered by the iPad, something tangible.

The emerging pattern in the category of collaboration indicated that working with others allowed students an avenue for conceptual discourse. Participants would survey, question, discover, clarify, and discuss their thoughts surrounding mathematical concepts and tasks with one another and their teachers. This element of collaboration was beneficial to all participants, but the observable benefit was more pronounced in lower-achieving or less independent students.

**Themes.** The theme of the scenario category is that critical thinking or a student’s problem-solving abilities and number sense ability work together for students to advance to the
next level. Within the affordance category, several different themes emerged. The subcategory of immediate feedback impacts students’ learning differently depending on the preschoolers’ ability. In the subcategory of verbal pronunciation, the affordance of pronunciation of the number enabled the student to have accuracy when ordering or identifying numbers. In the subcategory of quantity to written symbol, the most pronounced theme that occurred in each iPad app was connecting representation of object to written symbol to assist in number knowledge advancement. In the subcategory of visualization of touch counts, the theme was that, when practicing counting and learning numbers on the iPad, a touch count is imperative. In the grouping of ten categories, the theme was transitioning of one units to an unchanging unit of ten. In the collaboration category, the theme was communication impacts the learning process. In the concrete manipulative category, the theme was that additional affordances in specific materials were required for some preschoolers to learn.

**Concepts.** These themes were then translated into overarching conceptual labels (Strauss, 1990). The category of scenarios was given the concept of problem-solving skills. The category of affordances was labeled learning on the iPad. The category of grouping of ten was viewed as the concept of transitioning into base ten. The progress-based path category identified the concept of motivated engagement. The category of concrete manipulatives corresponded to the concept of tactile movement. The category of collaboration conveyed the concept of vocalization. This logical progression of research (the process of collecting raw data, creating narrative logs, coding narrative logs, categorizing these codes, identifying repeated patterns, translating these patterns into themes, then identifying the themes’ related concepts) is how the
researcher identified affordances accessed by participants, discussed in the results chapter of this dissertation. Finding the constraints followed the same process of analysis.

**Analysis of observational protocol.** The observation protocol provided details about each iPad session such as date, time, place, and what the child worked on. The document organized observational field notes for the iPad sessions, notes regarding improvement in interaction with iPad apps, and summarized affordances and constraints accessed by students. The observation text included affordances, features, or indicators that the child showed a physical reaction to. Student’s perceived mood toward and engagement with the iPad apps were recorded for authenticity. Recorded information was able to depict the nature of the change in participants’ number sense regarding numbers 1-20. The observation protocol organized information about students’ interactions with the iPad apps for the 14-week duration and was analyzed to identify emerging patterns and themes. Potential areas of interest to this research included accuracy, affordances and constraints.

**Analysis of ST Math report.** The ST Math student detail progress report generated by the ST Math software provided extra details about school sessions, home sessions, syllabus progress, and objective performance. The report illustrated domain overviews with bar graphs. This report furthermore presented specific objectives within domains, mastery percentages, and sessions used in correlation to each objective. The report offered details about student usage, gave average usage time per week, average progress per week, and total time in minutes interacting with ST Math.

**Analysis of field notes.** Field notes and artifacts were additionally collected to document more nuanced qualitative data in real time as the research unfolded. Field notes covered both students’ interactions with technology in addition to daily classroom mathematics activity.
Potential areas of interest for the collection of field notes and artifacts included the student’s perceived engagement, mood, ability to navigate the technology, and any other relevant contextual information not recorded elsewhere. The complete collection of field notes and artifacts document is available in Appendix Q. Field note data was analyzed to contextualize the nature of the change in participants’ number sense knowledge.

Data Analysis Conclusion

Ultimately, the focus of this research was firstly to identify emerging patterns and themes regarding preschoolers’ interactions with number sense iPad apps, and secondly to observe accessed affordances and constraints of number sense mathematics apps to provide insight on successful digital design for learning. This focus included emerging patterns for individuals to describe pattern progression over the study’s duration. When analyzing the affordance data, videos were reviewed to see what the students did on the iPad number sense apps and what affordances and constraints were most accessed. Videos of the students were watched and analyzed by reporting the affordances and constraints accessed; affordance and constraint coding for apps of interest is available in Appendix C. This analysis can identify which affordances and constraints were helpful and which were not. Additional information could include what affordances and constraints were accessed but did not result in a correct answer for the child. The data could produce design recommendations for app developers by looking at how these affordances and constraints affected the mastery of number concepts for preschoolers. A sample matrix table for recording student patterns associated with affordance and constraint access is available in Appendix T.
Chapter 4: Data Analysis and Results

Chapter 4 contains a restatement of the research questions, descriptions of iPad classroom implementation, and benefits of implementation as reported by teachers in the interviews. Additionally, this chapter provides the TEMA pre- and post-scores as well as the student activity pre- and post-scores. The ST Math summaries for Miss Day and Miss Newman’s classrooms are given. Additionally, the students’ video-recorded hours and total minutes spent on apps are included. Each participant’s case is described with basic characteristics of the student, academic descriptors, description of interactions with number sense apps, pre- and post-scores, ST Math progress, technology descriptors, and affordance descriptors. To further round out the research, contextual information collected from all parent questionnaires is provided. A section is devoted to artifacts, which includes lessons plans, pictures, and student work. The chapter ends with the affordance and constraints found in the research study.

Research Questions

1. How do 4- to 5-year-old preschoolers interact with mathematics-based number sense iPad apps for learning?

2. What affordances and constraints are accessed by 4- to 5-year-old preschoolers when interacting with number sense iPad apps, as observed via video recording?

Description of iPad Classroom Implementation as Reported in Teacher Interviews

The data was collected from two different classrooms within a school that serves mostly low-income Hispanic students. A total of 32 students from these two classrooms were invited to participate in this study by distributing parent permission slips at the beginning of January 2018. Twelve students’ parents agreed for their preschoolers to participate in the study: nine students were from Miss Newman’s room and three students were from Miss Day’s room. Out of the
twelve, six participants were purposefully selected for case descriptions. Although a variety of different apps were used throughout the study, the main app used in the classroom by the teachers was ST Math and, as a result, more interactions were observed on this app than any other app of interest. Both teachers used ST Math daily (V. Smith, Personal Communication, May 16, 2018) and incorporated the app into their regular classroom activities by including it in one of multiple classroom learning centers (M. Newman, Personal Communication, May 17, 2018). In Miss Newman’s room, the students used the iPad in both the morning and the evening centers, so most students would work with the iPad and ST Math twice a day (M. Newman, Personal Communication, May 17, 2018). Students in her class would play on the iPad for approximately 20 to 30 minutes a day (M. Newman, Personal Communication, May 16, 2018; V. Smith, Personal Communication, May 16, 2018). In Miss Day’s room, the iPads were used “once a day during our DI groups which is [the] differentiated instruction” (F. Day, Personal Communication, May 17, 2018). She explained that there were “four different small groups” in her classroom (F. Day, Personal Communication, May 17, 2018), “one group of children [was] on the iPad, while two groups [were] with teacher, and one group [was] doing an independent activity” (F. Day, Personal Communication, May 17, 2018). Miss Day’s classroom structure differed slightly from Miss Newman’s: her students only used the iPad an average of 15 minutes a day (F. Day, Personal Communication, May 17, 2018) and, since she had four groups, not every child in the class used the iPad every day.

Benefits of iPad Classroom Implementation as Reported by Teacher Interviews

Miss Newman reported that the iPad was “mainly used as a math tool” in her classroom (M. Newman, Personal Communication, May 17, 2018). She said that the students worked on ST Math individually, and she observed what skills the students were having trouble with. Then, she
often focused her lesson plan on or retaught the skills students struggled with. She liked the iPad as part of the curriculum because it allowed students to progress at their “own pace” (M. Newman, Personal Communication, May 17, 2018). Miss Day said that the iPad allowed the student to “just practice, it’s trial and error and so [the students] [got] to experience it on their own and it’s like a safe environment for them because they [didn’t] have everybody watching them” (F. Day Personal Communication, May 17, 2018). Miss Jones, Miss Day’s teaching assistant, agreed that the students liked iPad play and they could keep attempting until the answers are correct (M. Jones, Personal Communication, May 17, 2018). Miss Day stated that working on ST Math was “basically try it until you get it right” (F. Day, Personal Communication, May 17, 2018). Additionally, Miss Smith observed that ST Math could enhance critical thinking skills and assist students in successfully using technology. She continued by noting that it often taught the child to follow directions and could reinforce right and left (V. Smith, Personal, Communication May 16, 2018). Miss Jones alluded to the fact that students like to get JiJi where the penguin needed to go, so they can progress to the next level. The researcher indicated that students often did not want to stop playing because they wanted to get JiJi to the next level. For some students, progressing to the next level became almost a compulsion. Overall, the two teachers and the two teacher’s aides were positive about having ST Math as an instructional mathematics tool in their classrooms and expressed it collaborated well with their mathematics teaching (V. Smith, Personal Communication, May 16, 2018). The other comments from the teacher interviews will be discussed in individual cases when summarizing the personal, academic, and technology skills of students.

Table 4 provides the TEMA pre- and post-scores for the participants in the study. Jay had the highest increase in number sense knowledge from the beginning to the end of the study.
Next, Mike showed a significant increase in number understanding. David started out as a higher performing student and remained a higher performing student. Chase increased by 20 in his math ability score. Dana and Ann showed a slight increase in math ability scores. See Table 4 for the raw score, age equivalent, grade equivalent, percentile rank, and math ability score on the TEMA pre- and post-assessments, which provided a standardized assessment score. Table 5 depicts the pre- and post-scores for the student activity sheet, which provided an informal assessment. Table 6 offers details on ST Math summary reports for Miss Day’s classroom. Finally, Table 7 highlights details on ST Math summary reports for Miss Newman’s classroom.

Table 4 - TEMA Pre- and Post-scores.

<table>
<thead>
<tr>
<th>Student</th>
<th>Test</th>
<th>Raw Score</th>
<th>Age Equivalent</th>
<th>Grade Equivalent</th>
<th>Percentile</th>
<th>Math Ability Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jay</td>
<td>Pre-TEMA</td>
<td>8</td>
<td>3.9</td>
<td>Preschool</td>
<td>3</td>
<td>72</td>
</tr>
<tr>
<td>Jay</td>
<td>Post-TEMA</td>
<td>33</td>
<td>6.0</td>
<td>1.0</td>
<td>79</td>
<td>112</td>
</tr>
<tr>
<td>Mike</td>
<td>Pre-TEMA</td>
<td>6</td>
<td>3.6</td>
<td>Preschool</td>
<td>6</td>
<td>77</td>
</tr>
<tr>
<td>Mike</td>
<td>Post-TEMA</td>
<td>23</td>
<td>5.3</td>
<td>K2</td>
<td>68</td>
<td>107</td>
</tr>
<tr>
<td>David</td>
<td>Pre-TEMA</td>
<td>16</td>
<td>4.6</td>
<td>Preschool</td>
<td>25</td>
<td>90</td>
</tr>
<tr>
<td>David</td>
<td>Post-TEMA</td>
<td>22</td>
<td>5.0</td>
<td>K</td>
<td>37</td>
<td>95</td>
</tr>
<tr>
<td>Chase</td>
<td>Pre-TEMA</td>
<td>4</td>
<td>3.3</td>
<td>Preschool</td>
<td>1</td>
<td>65</td>
</tr>
<tr>
<td>Chase</td>
<td>Post-TEMA</td>
<td>16</td>
<td>4.6</td>
<td>Preschool</td>
<td>16</td>
<td>85</td>
</tr>
<tr>
<td>Dana</td>
<td>Pre-TEMA</td>
<td>4</td>
<td>3.3</td>
<td>Preschool</td>
<td>6</td>
<td>77</td>
</tr>
<tr>
<td>Dana</td>
<td>Post-TEMA</td>
<td>7</td>
<td>3.9</td>
<td>Preschool</td>
<td>12</td>
<td>82</td>
</tr>
<tr>
<td>Ann</td>
<td>Pre-TEMA</td>
<td>3</td>
<td>3.0</td>
<td>Preschool</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>Ann</td>
<td>Post-TEMA</td>
<td>7</td>
<td>3.9</td>
<td>Preschool</td>
<td>4</td>
<td>74</td>
</tr>
</tbody>
</table>
Table 5 - Student Activity Pre- and Post-scores.

<table>
<thead>
<tr>
<th>Student</th>
<th>Test</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mike</td>
<td>Pre-Student Activity</td>
<td>30%</td>
</tr>
<tr>
<td>Mike</td>
<td>Post-Student Activity</td>
<td>90%</td>
</tr>
<tr>
<td>Dana</td>
<td>Pre-Student Activity</td>
<td>30%</td>
</tr>
<tr>
<td>Dana</td>
<td>Post-Student Activity</td>
<td>90%</td>
</tr>
<tr>
<td>Ann</td>
<td>Pre-Student Activity</td>
<td>20%</td>
</tr>
<tr>
<td>Ann</td>
<td>Post-Student Activity</td>
<td>50%</td>
</tr>
<tr>
<td>David</td>
<td>Pre-Student Activity</td>
<td>90%</td>
</tr>
<tr>
<td>David</td>
<td>Post-Student Activity</td>
<td>99.9%</td>
</tr>
<tr>
<td>Chase</td>
<td>Pre-Student Activity</td>
<td>30%</td>
</tr>
<tr>
<td>Chase</td>
<td>Post-Student Activity</td>
<td>70%</td>
</tr>
<tr>
<td>Jay</td>
<td>Pre-Student Activity</td>
<td>60%</td>
</tr>
<tr>
<td>Jay</td>
<td>Post-Student Activity</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 6 - ST Math Summary Reports for Day’s Classroom.

<table>
<thead>
<tr>
<th>Name</th>
<th>School Sessions</th>
<th>Home Sessions</th>
<th>Syllabus Progress</th>
<th>Average Time per Week in minutes</th>
<th>Average Progress per Week in percent</th>
<th>Total Time for Year in minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mike</td>
<td>87</td>
<td>96</td>
<td>100%</td>
<td>79</td>
<td>2.9%</td>
<td>2,680</td>
</tr>
<tr>
<td>Jay</td>
<td>105</td>
<td>5</td>
<td>98%</td>
<td>45</td>
<td>2.8%</td>
<td>1,532</td>
</tr>
<tr>
<td>Class  Average Day</td>
<td>75</td>
<td>17</td>
<td>60%</td>
<td>65</td>
<td>2%</td>
<td>1,849</td>
</tr>
</tbody>
</table>

Table 7 - ST Math Summary Reports for Newman’s Classroom.

<table>
<thead>
<tr>
<th>Name</th>
<th>School Sessions</th>
<th>Home Sessions</th>
<th>Syllabus Progress</th>
<th>Average Time per Week in minutes</th>
<th>Average Progress per Week in percent</th>
<th>Total Time for Year in minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dana</td>
<td>142</td>
<td>50</td>
<td>55%</td>
<td>104</td>
<td>1.5%</td>
<td>3,637</td>
</tr>
<tr>
<td>Ann</td>
<td>100</td>
<td>9</td>
<td>37%</td>
<td>43</td>
<td>1%</td>
<td>1,511</td>
</tr>
<tr>
<td>David</td>
<td>139</td>
<td>24</td>
<td>78%</td>
<td>53</td>
<td>2.2%</td>
<td>1,856</td>
</tr>
<tr>
<td>Chase</td>
<td>134</td>
<td>4</td>
<td>37%</td>
<td>63</td>
<td>1%</td>
<td>2,206</td>
</tr>
<tr>
<td>Class  Average Newman</td>
<td>116</td>
<td>17</td>
<td>52%</td>
<td>59</td>
<td>1.5%</td>
<td>2,051</td>
</tr>
</tbody>
</table>
The Case of Mike

**Basic characteristics of Mike.** Mike was an African American who identified as a male. At the start of the research, he was four years and eight months old; at the end of the research session, he was four years and eleven months old. He was the fourth youngest of the participating students. Mike had a speech impediment, which caused some difficulty in communicating with others. His teacher described that he will try at least three times to get his point across (F. Day, Personal Communication, May 17, 2018). He was very patient and did not easily become aggravated if someone could not understand him. The researcher noted in field observations that, if he was not understood on the third time, he would simply smile and go on without it upsetting him or distracting him from his work. On the other hand, his teacher noted that if he was very adamant about something he will persist verbally (F. Day, Personal Communication, May 17, 2018).

The teacher described Mike as having “a lot of integrity.” Miss Day commented that “he [wanted] to do the right thing. He [wanted] to know that his friends [were] doing the right things, being on task” (F. Day, Personal Communication, May 17, 2018). Additionally, he aided the classroom teacher in this aspect (F. Day, Personal Communication, May 17, 2018). He was very good at regulating himself and others; for example, he regularly reminded his classmates it was time for them to be quiet because the teacher was waiting (F. Day, Personal Communication, May 17, 2018). The researcher noted through classroom observation that he was mostly always on task and directing other students to do the same. His speech impediment did not seem to discourage him from participating in a leadership role with his peers in any way. The teacher’s aide commented that “he [paid] attention to the details” and “he [wanted] to learn” (M. Jones, Personal Communication, May 17, 2018).
**Academic descriptors.** It was stated by the teacher that Mike was one of the lowest students in her classroom. However, she acknowledged that he had improved from the beginning of the school year and that, by the school year’s close, he was in the second highest group overall in both literacy and math (F. Day, Personal Communication, May 17, 2018)). In math, it was evident that he excelled with the use of the ST Math app (F. Day, Personal Communication, May 17, 2018)). He was the highest-scoring student on the ST Math app in the class (F. Day, Personal Communication, May 17, 2018)). He loved to work with ST Math and “he [was] very engaged in it and he [wanted] to know if he [had] a problem he [would] come to you and he [would] ask” (F. Day, Personal Communication, May 17, 2018)). The researcher remarked in field notes that Mike wanted to deduce the answer correctly when playing with ST Math. The researcher also noted this characteristic when Mike shared answers in small or large group settings. Mike always wanted to answer questions correctly to the point that, if he was incorrect, there were observable physical responses. He would literally put his small hand on his head and shake it in disappointment and the researcher would reinforce that it was ok to be wrong sometimes.

**Description of interactions with number sense apps.** Mike displayed advanced interactions on all fronts when working with the number sense iPad apps. He was able to meet all the class objectives in ST Math and maintained a favorable attitude about working on the iPad. He did not have any trouble with technological navigation, and he operated the technology with strong touch count skills. After Mike played for a while, it was observed via video recording that JiJi became associated with achievement. Mike would verbally show excitement when JiJi moved to the next level. This gave him instant feedback on his correct answer; he used expressions such as “wow!,” “yeah!,” and “JiJi!” His interactions with the game could become competitive at times. He would play for longer increments than his peers and always wanted to
get JiJi to the next level. He liked the unknown element of seeing what was next for JiJi.

Compared to other children, he interacted with the technology for more minutes, and had a higher number of sessions both in and out of school. Table 8 is summary of Mike’s total interaction time with the 4 apps used.

<table>
<thead>
<tr>
<th>Apps</th>
<th>ST Math</th>
<th>ToDo Math</th>
<th>Math Shelf</th>
<th>Montessori Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mike</td>
<td>2,014 minutes</td>
<td>19 minutes</td>
<td>23 minutes</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Average for Participants</td>
<td>1,248 minutes</td>
<td>19 minutes</td>
<td>19 minutes</td>
<td>43 minutes</td>
</tr>
</tbody>
</table>

**Pre- and post-scores.** Mike was purposely selected as a participant for this research because his scores on the TEMA test reflected his growth during the year. His TEMA pre-scores reflected a raw score of six, an age equivalent of three years six months, and a grade equivalent of preschool level. On the TEMA pre-test, he scored at the sixth percentile. This percentile rank is a derived score that illustrates the percentage that occurs at or below a raw score on the normal-bell curve distribution. Mike only performed better than six percent of the students who took the TEMA on the pre-test. The TEMA reported that his math ability score was a 77. Norms for the TEMA are presented in terms of standard scores having a mean of 100 and standard deviation of 15. Therefore, Mike’s score was more than one standard deviation below the mean. A second pre-test score assessment was collected at the beginning of the study in the form of a student activity sheet. This assessment was not a standardized test, but a more practical student activity which gave the researcher insight on the student’s math ability. Mike attained a score of 30% on this student activity.
On the TEMA post-test, his raw score was a twenty-three, and his age equivalent was five years three months, with a grade equivalent of kindergarten second month. He moved from the sixth percentile to the sixty-eight percentile with a math ability score of 107. His math ability score was above mean, which shows a gain in mathematical skills. On the post-test student activity sheet, which was a more informal assessment than the TEMA, Mike improved his score drastically, increasing from an initial thirty percent accuracy to ninety percent accuracy. Both assessment scores from the pre- and post-tests indicated that Mike increased significantly in foundational mathematics skills.

**ST Math progress.** The student detail report given by ST Math showed evidence that reinforces the pre- and post-test scores. Mike was able to master all his assigned objectives and received a 100% on his ST Math progress. In fact, the teacher’s aide said that “[he was] the first one in the classroom to finish JiJi” (M. Jones, Personal Communication, May 17, 2018). She described this progress as happening overnight: “all of sudden” (M. Jones, Personal Communication, May 17, 2018). She continued to anecdotally observe that Mike progressed from 40% to 80% in one week, and then quickly advanced to 90%, and then 100% (M. Jones, Personal Communication, May 17, 2018). She concluded that “then it just seemed like he grasped the ideas. It was like one day it all clicked for him. He just flew through [the different concepts]” (M. Jones, Personal Communication, May 17, 2018). The student detail report indicated that Mike played with the ST Math app an average of 79 minutes a week, which is above the average class time by 14 minutes. His average progress per week was 2.9% compared to the class average of 2%. He worked a total of 2,680 minutes, exceeding his peers’ average by 831 minutes. The report indicated that he had 87 school sessions and 96 home sessions.
The report also clarified that Mike met all his domain objectives in counting and cardinality, operations and algebraic thinking, number and operations in base ten, geometry, and measurement and data. In the counting and cardinality domain, he obtained an 100% on the objective numbers and objects to 5 after five tries. He accomplished the subitizing objective with a 100% in six sessions. The numbers and objects to 10 was mastered with a 100% within six tries. He received a 94% on the greater than, less than, and equal to standard during two sessions. On the numbers and objects to 20, his score was 100% after four interactions with app. A 100% was gained after three attempts on the comparing numbers sections.

In the domain of operations and algebraic thinking, he obtained an 100% with only three stabs at understanding addition and subtraction within 5, understanding addition and subtraction within 10. It took him eight attempts of trial and error to accomplish the making 10 and number pairs. In this domain, he had the most trouble with the challenge objective: he only scored a 51% following ten attempts. In this domain, he was still able to achieve an overall score of 85%, 10% greater than the curriculum goal.

The number and operations in base ten domain consisted of three objectives: introduction to the number line, foundations of place value, and numbers and courting to 100. Respectively, Mike received a 100% with four, four, and five practice sessions. In the next domain of geometry, Mike mastered all the set goals with 100% which consisted of exploring shapes, analyzing shapes, composing shapes, and position. His number of attempts were two, two, five, and eight with respect to these standards. In the last domain of measurement and data, he once again received 100% on all the included objectives of measurable attributes, reasoning with attributes, and sorting and classifying with attempts numbering two, two, and seven. Table 9 denotes Mike’s ST Math student detail report.
### Table 9 - ST Math Student Detail Report for Mike from February to May.

<table>
<thead>
<tr>
<th>Date</th>
<th>School Sessions</th>
<th>Home Sessions</th>
<th>Syllabus Progress</th>
<th>Average Time/Week</th>
<th>Average Progress/Week</th>
<th>Total Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/20/18</td>
<td>30</td>
<td>5</td>
<td>21%</td>
<td>30 minutes</td>
<td>0.9%</td>
<td>666 minutes</td>
</tr>
<tr>
<td>5/21/18</td>
<td>87</td>
<td>96</td>
<td>100%</td>
<td>79 minutes</td>
<td>2.9%</td>
<td>2,680 minutes</td>
</tr>
<tr>
<td>Class</td>
<td>75</td>
<td>17</td>
<td>60%</td>
<td>65 minutes</td>
<td>2%</td>
<td>1,849 minutes</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Technology descriptors.** The information provided in this section was denoted by Mike’s parent questionnaire collected during the study. Mike’s parent questionnaire illustrated that technology was used in their home quite frequently and that Mike was very familiar with and acquainted to the use of technology such as the computer, video games, and a cell phone. His parents indicated that they knew how to solve their own technical problems, learn technology easily, and frequently play around with technology. They also scored themselves high on understanding new technologies and the use of different technologies. They encouraged the use of technology at school and home to learn pre-school concepts. Mike had 96 home sessions as reported by ST Math, which was the highest number of home sessions among all participants. His parents ranked technology as the most important need facing schools today. They assisted Mike in experiencing technology for learning. His parents stated that he used technology at home, in the car, at school, and while waiting in general.

This supports the idea that Mike’s home environment fostered technology usage and that it was frequently explored at home. Therefore, this knowledge provided insight to Mike’s familiarity and comfort with technology, which the researcher observed during his iPad app sessions. His parents indicated that he played with technology at home nearly 2 hours a day. They revealed that he easily learned new technology and, for the most part, Mike could solve his
own technology issues. The researcher observed this to be the case as well when working with Mike in the iPad sessions.

Mike’s parents responded that he could take pictures and selfies, watch educational and entertainment cartoons or videos, play with educational games, and communicate with friends and family via FaceTime. The researcher quickly determined that Mike was advanced in his technology skills, because he could power on and login into the iPad by remembering the key code. He could also start the videotaping within the iPad and navigate to the selected app and between apps. Additionally, he turned up and down the volume and followed both visual and auditory direction indicators without any trouble. During the research, he displayed adequate ability to focus and complete his 10- to 30-minute sessions without being off-task. Both the parents and the researcher agreed that Mike would not stop playing the iPad unless you made him stop or the battery ran out.

**Affordance descriptors.** Since Mike was an advanced learner with excellent technology skills and above average number sense capabilities, he did not use as many affordances as other children. He seemed to progress through the app’s levels with a sense of intuition which was not always apparent with the other students. Most of the affordances he used were on the more challenging levels of ST Math. Mike’s affordance usage was most prevalent when he began learning to add and subtract numbers at the end of the study. He also used affordances in the geometry sessions of ST Math when dealing with symmetry. A total of 7 hours 25 minutes and 55 seconds of documented videotaping footage was collected on Mike’s interactions with the iPad.

The following paragraphs will discuss some pronounced examples of affordances Mike accessed. A simple affordance Mike utilized when practicing counting on the ToDo and ST Math
apps was that the on-screen object would shake or change color as he touched it; Mike would then verbally say the number attached to the representation. This was an illustration of tactile gesture that allowed Mike to learn numbers and objects up to 20.

When adding sums of 5 and 10 on two visual ten frame diagrams, Mike would first count the unshaded boxes in the first ten frames to determine how many more boxes should be shaded in the second ten frames to make the sums of 5 or 10. On sums adding up to 5, Mike used his subitizing skills, just knowing how many to shade in the second ten frame to achieve the correct answer. On the sums adding up to 10, Mike would first count the unshaded boxes in the first ten frames. He would then touch the correct amount of boxes in the second ten frames. As he touched the boxes, they would fill with different colors. After he chose the correct number of boxes, he would press the enter button. The app would then animate the boxes and pull them together; for example, if the problem was adding 2 and 8 to make 10, the ten frames with 2 and the ten frames with 8 would be pulled together to show a visual display of 10. The full ten frames would then elongate, placing the ten boxes in a single-file horizontal line, effectively creating a number line with the boxes. This function primes students to recognize number lines and varying representations of the same quantity. If it was correct, JiJi would run across the screen to indicate that the participant was successful, and the next question would begin.

The level of ST Math entitled “bouncing shoes to 10” covers addition to 10. During this level, the screen would have a certain number of red shoes that the student had to count. Then, the child had to select characters with different numbers of legs to fill the displayed red shoes. This allowed the student to have practice adding with a visualization of the right answer. So, if there were four red shoes on the screen, the child would need to select the character with four legs or the child would select a character with 2 legs twice. This provided an illustration that 2 +
2 = 4. As Mike worked through this activity on the app, he utilized the affordance of connecting visual representation with quantity.

In general, the app provided a variety of affordances for Mike, such as individualized learning, by providing interactive virtual manipulatives in a free-moving form that was often animated. The app afforded Mike and his classmates the opportunities to engage in mathematics in a positive and fun way. Since Mike completed all his assigned objectives in ST Math, the app afforded him the opportunity to order numbers, match representation of quantity to written symbol, learn order quantities of numbers, learn smallest to largest, practice counting, adding and subtracting foundational skills, patterns, basic statistics graphs, and geometry concepts.
The Case of Dana

**Basic characteristics of Dana.** Dana was the youngest in the class; she barely made the preschool cutoff date. She was also the youngest in her family (V. Smith, Personal Communication, May 16, 2018). She was a Hispanic female who the researcher would describe as shy and timid. At the beginning of the project she was four years and five months old; at the end of the research she was four years and eight months old. Miss Newman remarked that “she [was] very codependent on other people” (M. Newman, Personal Communication, May 16, 2018). The teacher also stated that “all she [wanted] to do [was] socialize so she [had] a hard time focusing on academics because all she [wanted] to do is socialize with friends” (M. Newman, Personal Communication, May 16, 2018). The teacher’s aide suggested that she must feel secure in her educational environment to perform (V. Smith, Personal Communication, May 16, 2018). Field notes and video depicted Dana often exhibited avoidance characteristics if she felt uncomfortable or if the app game was too hard for her.

**Academic descriptors.** Dana was described by her teacher as being on the lower end in academics (M. Newman, Personal Communication, May 16, 2018). Her teacher depicted her as having low mathematical ability because “she [didn’t] really care for the iPad, but she [didn’t] really care for academics in general” (M. Newman, Personal Communication, May 16, 2018). The researcher noted that, if the curriculum on ST Math was too difficult for Dana, she would avoid interaction with the app or not give it a chance. This observation was clarified by the teacher’s aide’s comment about Dana needing positive reinforcement to succeed academically. The researcher remarked for Dana to succeed in learning she needed one-on-one instruction or the aid of a peer or classmate to help her understand concepts. The researcher and teacher’s aide observed that Dana often confused the numbers 6 and 9 (V. Smith, Personal Communication,
May 16, 2018). This misstep persisted in Dana’s performance throughout the research study. Even though Dana had lower mathematical skills, the researcher observed her playing cashier in one of the learning centers. She had the toy cash register and was checking out other students with grocery items. In this candid interaction, Dana explored mathematics in her play within a secure and familiar setting.

**Description of interactions with number sense apps.** Dana was a strong example of a child who tried to use ST Math as a supplemental tutoring tool. She accrued significant time using the iPad in both the home and school settings. In fact, she had the second highest number of home school sessions. However, she needed to work in collaboration with others to benefit from the experiences of learning on the iPad. She would sometimes need assistance with her touch counts. For example, she would forget to hit the enter button and required reminding. Additionally, if the enter button moved she would sometimes need assistance finding it on the screen. As the game scenarios and rules changed, Dana had trouble following along. This difficulty had been observed by other researchers (Rutherford et al, 2014). Her attitude became influenced by the level of the game she played. If she found the math puzzles too difficult, she avoided playing and always needed reinforcement to progress. She did not seem to connect to JiJi or the element of getting JiJi to the next level, nor did she exhibit competitive behaviors. She enjoyed playing the non-challenging levels of ST Math’s software. She did use the app for drill and practice and her scores reflected that it bridged some understanding for her. She mostly enjoyed the counting exercises and the tracing tasks because they were a level in which she could succeed. Table 10 below summarizes Dana’s total interaction time with the 4 apps used and includes details on Dana’s interactions with the number sense apps.
Table 10 - Dana’s Interactions with Number Sense Apps from February to May

<table>
<thead>
<tr>
<th>Apps</th>
<th>ST Math</th>
<th>ToDo Math</th>
<th>Math Shelf</th>
<th>Montessori Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dana</td>
<td>2,238 minutes</td>
<td>9 minutes</td>
<td>35 minutes</td>
<td>80 minutes</td>
</tr>
<tr>
<td>Average for Participants</td>
<td>1,248 minutes</td>
<td>19 minutes</td>
<td>19 minutes</td>
<td>43 minutes</td>
</tr>
</tbody>
</table>

Pre- and post-scores. Dana was selected for the case for trifold reasons: she was the youngest in the class, fell in the lower academic rank in mathematics, and displayed a reluctance to use ST Math’s more challenging modules. She additionally displayed some difficulty in operating the touch screen device. Out of all participants, Dana displayed the greatest need for assistance on the iPad. Her TEMA pre-score assessment was a raw score of 4, age equivalent of three years and three months, and a grade equivalent of preschool. She scored at the sixth percentile on the TEMA pre-test, with a math ability score of 77. The second pre-test score was taken from the student activity worksheet; she received a 30%. Post-test scores on the TEMA reported that she had a raw score of 7, with an age equivalent of three years nine months. She was still preforming at preschool level. Her age equivalence increased by six months during the 14-week intervention. She finished at the twelfth percentile, reflecting a math ability score of 82. Norms scores for the TEMA have a mean of 100 and a standard deviation of 15. Dana’s scores reflected that she did not move from the pre- to post-test, staying between 2 and 1 standard deviation below the mean. She had a significant gain on the informal student activity sheet with a post-test score of 90%. The researcher felt this could be due to Dana’s comfort level within a less structured, non-standardized assessment wherein Dana felt more secure with the parameters.

ST Math progress. Dana accomplished 55% of the objectives assigned in the ST Math app, just over the class average of 52%. Most of her progress was due to consistent assistance
from parents, siblings, teachers, and peers. She completed 142 in-school mathematics sessions and 50 home school sessions on ST Math. Dana practiced at home more than almost any other student in her class: her home sessions were the second highest out of all the students. The class average for home sessions was seventeen. In field notes, the researcher recorded that Dana commented that she worked with parents and older siblings at home on ST Math, particularly to learn numbers 10-20. She worked a total of 3,637 minutes and an average of 104 minutes a week. The class average total minutes was 2,051 minutes with an average of 59 minutes a week. She progressed approximately 1.5 % per week, consistent with the class average. However, Dana necessitated one-on-one assistance to progress through the levels. She would literally wait on help to answer questions. She would not engage in the activity alone.

Dana did not master any of the five main domains in ST Math. Among all ST Math’s domains, she completed the most objectives in the counting and cardinality domains. She was able to master the following domains with 100% accuracy: numbers and objects to 5, subitizing, numbers and objects to 10, greater than, less than, and equal to, and numbers and objects to 20. Respectively, Dana’s number of tries were 10, 7, 13, 3, and 14. In the operations and algebraic thinking domain, she struggled significantly in understanding addition and subtraction within 10. The researcher noted that Dana did not appear ready for addition and subtraction. She required practice with basic foundational skills of identifying, ordering, counting, and number recognition. Dana attempted the addition and subtraction within 10 modules 21 times before passing it with 100%. She met one objective, introduction to the number line, in the number and operation in base ten domain. She attempted this section 8 times before successful completion. In the geometry domain, she worked on the objectives exploring shapes and analyzing shapes. She had the most success with analyzing shapes but had to attempt exploring shapes five times. It
was noted that the entirety of the objectives Dana met were achieved with assistance; no modules were successfully completed independently. Table 11 covers Dana’s ST Math student detail report.

Table 11 - ST Math Student Detail Report for Dana from February to May.

<table>
<thead>
<tr>
<th>Date</th>
<th>School Sessions</th>
<th>Home Sessions</th>
<th>Syllabus Progress</th>
<th>Average Time/Week</th>
<th>Average Progress/Week</th>
<th>Total Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/20/18</td>
<td>70</td>
<td>5</td>
<td>18%</td>
<td>62 min</td>
<td>0.7%</td>
<td>1,399 min</td>
</tr>
<tr>
<td>5/21/18</td>
<td>142</td>
<td>50</td>
<td>55%</td>
<td>104 min</td>
<td>1.5%</td>
<td>3,637 min</td>
</tr>
<tr>
<td>Class</td>
<td>116</td>
<td>17</td>
<td>52%</td>
<td>59 min</td>
<td>1.5%</td>
<td>2,051 min</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Technology descriptors.** A total of 6 hours 10 minutes and 7 seconds were recorded that captured Dana’s interactions with the iPad’s apps. According to the observation protocol, Dana displayed weaker technology skills. She was unable to turn the iPad on by herself, adjust the volume on the iPad, or troubleshoot her own problems. Occasionally, Dana was able to successfully follow indicators provided by the app and voice directions or questions. She frequently could not complete her 10-minute sessions, especially when JiJi’s levels were challenging. She could not consistently navigate between apps and would sometimes forget her ST Math password, requiring multiple attempts when logging into the program. Her parents described their technology knowledge as average. Dana indicated that she often played with technology when assisted by an older sibling. She could become frustrated when working independently. Both Miss Newman and her parents reported that she would choose other activities over playing with the iPad.

Although there was significant evidence that Dana engaged with ST Math as a supplemental learning tool in earnest, she displayed hesitance and uncertainty when the context
of her learning became unfamiliar. This reinforces the researcher’s aforementioned observations that Dana’s performance with the pre-and post-student activity sheet reflected her enhanced security with her knowledge when she felt comfortable within the context of her learning or learning environment. Thus, when the context of JiJi’s adventures changed, this appeared to affect Dana’s confidence in her knowledge. The change in the app’s context for learning seemed to hamper Dana’s ability to recognize the app’s signifiers and cues as readily as other participants.

Affordance descriptors. Due to Dana’s lower academic understanding and weaker technology skills, often affordances that were provide by the app did not help her answer problems correctly. For example, ST Math has a section that displays number symbols with corresponding sticks in shape of that number. Dana needed to be shown several times how to count the sticks to correctly identify the number by the quantity of the sticks. She was not quick to pick up on cues that were available through the app. Even though the iPad app provided affordances, her lack of understanding prevented her from accessing them, or she chose to ignore them. The teacher, teacher’s aide, other peers, or the researcher would have to show her how to attain the correct answers. She did not appear to benefit as much from the technology because she needed constant reinforcement. One-on-one individualized instruction was necessary for Dana to advance in academics. One of Dana’s favorite app tasks was that of tracing numbers; she enjoyed the tracing activities within the Montessori App and the ToDo app. The researcher concluded it was a safe, easy task for her to learn to identify numbers 1-20.

Considering Dana’s affection for the iPad’s tracing tasks, she accessed many affordances within these activities, such as linking visual representation of quantity while she traced the written symbol. This afforded her an opportunity to identify numerical representations by linking
them with their verbal counterparts; furthermore, the ToDo app specifically included a visual representation of quantity with this link between numeral and pronunciation. She would trace the written symbol with signifiers that provided directions; this allowed her the opportunity to learn written symbols. During these activities, the app would pronounce the number after it was traced. Therefore, this allowed Dana to connect written symbols to verbal pronunciation. Within these tasks, students were awarded with celebration stars, providing cues that Dana gave the correct answer.

It took Dana a longer amount of time to learn numbers 1-20. It was observed with numbers 1-5 that MathShelf’s approach to connecting representation with written number worked best for Dana. This approach was much like touch math in that the symbols for the numbers were shown with corresponding circles. For example, the “1” symbol had one small circle at the top; the “2” symbol had two small circles: one at the top and one at the bottom. This afforded her the opportunity to see the quantity and the symbol at the same time. Additionally, the circles changed color when touched, allowing her to count the circles and identify the numbers. Something about MathShelf’s specific approach of integrating quantity with symbol (as opposed to visually separating the two) permitted Dana to effectively acquire these concepts.

At the beginning of the research, she was most successful when quantity was accompanied by the identification of the number.

The most prolific affordances among those Dana accessed were simplistic touch counts in which objects moved, changed color, or provided an audio response (most often, pronunciation). The reason she accessed these affordances the most is because it took her extra time on task to learn number 1-20. Her ST Math student detail report reviled that she worked the number and objects to 5 ten times and the numbers and objects to 10 thirteen times for mastery. She worked
best with a simple display. This affordance often connected visual representation of quantity to written symbol.

The Case of Ann

**Basic characteristics of Ann.** Ann is a female from a Hispanic background; she was four years and nine months old at the beginning of the study and five years old at the end of the study. The aide described her as being “a girly girl” and commented that she is very pretty (V. Smith, Personal Communication May 16, 2018). Ann had long dark hair that reached below her waist and frequently wore bows, ear rings, and rings. She always participated in different dress-up days at school. She was animated with her gestures and particular about her desires, often wearing a big smile and exuding happiness. She was social and preferred to work with others. She liked pretty things and could be motivated to work if you pampered her by letting her choose color preference. The aide’s example of motivation for Ann was “oh look at the beautiful butterflies! How many butterflies are there?” (V. Smith, Personal Communication May 16, 2018). The aide went on to say that she required connection with something that appealed to her or she would not do it (V. Smith, Personal Communication May 16, 2018). For instance, the researcher recorded in field notes that she consistently wanted to play with the purple iPad and the matching purple styling pen. Ann was demanding for a four-year-old and was very opinionated. For example, if she did not want to play the iPad, she would fold her arms and kick her feet in the chair and tell you “NO.” On other occasions, she would demand “I NEED HELP” with a pointed finger tapping on the desk in rhythm with her words.

**Academic descriptors.** Miss Newman expressed that Ann was very low at the at the beginning of the year. She “would lose confidence very easily to the point where she [would] start crying” (M. Newman, Personal Commutation, May 17, 2018). The teacher also commented
that “she [didn’t] want to do it by herself. Even if she [could] do it she [thought] she [couldn’t]” (M. Newman, Personal Communication, May 17, 2018). The aide said that “she started out very low, she started out not being interested in anything, math or anything” (V. Smith, Personal Communication May 16, 2018). In general, the researcher observed that Ann preferred the use of concrete manipulatives to understand mathematical concepts. She noted that Ann was adamant about needing visuals to master materials.

**Description of interactions with number sense apps.** Ann’s attitude fluctuated from day to day and this interfered with her interactions with the iPad. Her knowledge of the iPad’s different components advanced significantly over the course of both the school year and the study’s duration. She became more familiar with the technology and gained some technological skills. She would often choose other activities over playing with the iPad. She was not competitive with the app, and she would have liked JiJi better if it had a bow in its hair or cute clothes. She had to have concrete manipulatives in addition to the affordances offered by the iPad app’s games. She did not exhibit any trouble navigating her touch counts’ objects on the screen, and she had strong eye-hand coordination. Ann was vocal in demanding assistance if she misunderstood the concepts but performed more consistently with touch counts. Table 12 summarizes Ann’s total interaction time with the 4 apps used.

*Table 12 - Ann’s Interactions with Number Sense Apps from February to May.*

<table>
<thead>
<tr>
<th>Apps</th>
<th>ST Math</th>
<th>ToDo Math</th>
<th>Math Shelf</th>
<th>Montessori Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ann</td>
<td>650 minutes</td>
<td>19 minutes</td>
<td>27 minutes</td>
<td>65 minutes</td>
</tr>
<tr>
<td>Average for Participants</td>
<td>1,248 minutes</td>
<td>19 minutes</td>
<td>19 minutes</td>
<td>43 minutes</td>
</tr>
</tbody>
</table>
Pre- and post-scores. On the TEMA pre-test, Ann performed at a preschool grade equivalent and her age equivalent was three years. She had a raw score of 3 and scored at the second percentile, with a math ability score of 70. On the student activity worksheet at the start of the study, she made a 20%. At the end of the study, the TEMA post-test indicated that she was still at a preschool grade equivalent and had only gained .9 months in age equivalency. She moved up two percentile and finished the session at the fourth percentile. At the study’s conclusion, her math ability score was 74. Ann’s score did not fluctuate significantly, and she remained between 2 and 1 standard deviations below the mean throughout the project. On the post-test student activity worksheet, she scored a 50%.

ST Math progress. The ST Math progress report stated that Ann completed 37% of the objectives. She played a total of 1,511 minutes, averaging 43 minutes a week. She finished 100 school sessions and worked in the domains of counting and cardinality, operations and algebraic thinking, and geometry. She did not work on any of the objectives in the domain of numbers and operations in base ten or measurement and data. Ann’s mastery of the apps’ concepts required significant attempts or repetitions of the lesson. For example, she had to play numbers and objects to 5 thirty-six times to pass this level with 100% accuracy. Additionally, she had to play numbers and objects to 10 twenty-three times before achieving complete accuracy. Table 13 summarizes Ann’s ST Math student detail reports.

<table>
<thead>
<tr>
<th>Date</th>
<th>School Sessions</th>
<th>Home Sessions</th>
<th>Syllabus Progress</th>
<th>Average Time/Week</th>
<th>Average Progress/Week</th>
<th>Total Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/20/18</td>
<td>59</td>
<td>9</td>
<td>19%</td>
<td>38 min</td>
<td>0.8%</td>
<td>861 min</td>
</tr>
<tr>
<td>5/21/18</td>
<td>100</td>
<td>9</td>
<td>37%</td>
<td>43 min</td>
<td>1.0%</td>
<td>1,511 min</td>
</tr>
<tr>
<td>Class Average</td>
<td>116</td>
<td>17</td>
<td>52%</td>
<td>59 min</td>
<td>1.5%</td>
<td>2,051 min</td>
</tr>
</tbody>
</table>

Table 13 - ST Math Student Detail Report for Ann from February to May.
Technology descriptors. At the school year’s beginning, Ann did not like technology. The aide noted that she was not interested in any technology until after encountering ST Math. The aide articulated that, from the start of the school year to the study’s close, Ann had progressed to the point that she could turn the iPad off, log off, log in, and follow directions given by the app (V. Smith, Personal Communication, May 16, 2018). The researcher noted that Ann liked to take selfies and could run the video options within the iPad with ease. Ann’s parents’ questionnaire revealed that they felt Ann had better technology skills than they did. Her parents indicated that Ann could solve her own technical problems and learned technology easily. They said she played with and utilized different technologies (Parent Survey question 3). She accessed technology at home and completed 9 home session on ST Math, which is significantly below the class average of 17. Both parents encouraged and assisted Ann when playing with technology, and she appeared to have an intuitive sense of technology when given opportunities to explore; however, this curiosity for the iPad did not necessarily translate to a curiosity for the mathematics apps.

Affordance descriptors. Often, the affordances provided by the apps were not enough for Ann to answer questions correctly. She was the only student in the study who constantly used a concrete manipulative alongside app affordances to work through the apps’ levels. She had low number sense skills and had to have visual aids assisting her indefinitely with the task at hand. She used cards, blocks, the hundred number chart, number line chart, and toy characters to help her solve problems. She not only used them as mathematics tools, but also frequently created play scenarios. When working on identifying numbers and representations on ST Math, due to her underdeveloped number sense, Ann would use the additional visual aids. These visuals consisted of cards with the number and corresponding quantity on the card. She would have to
touch one object on the card and one object on the screen to arrive at the correct corresponding quantity of the number in question. She developed her own accommodations to get the correct answer, without really understanding or knowing the number. She was performing a modified matching activity with the card and the iPad to arrive at the correct answer. Through her actions, Ann appeared to require physicality, preferably manipulatives with textural distinctions, to internalize numerical quantity. She appeared less able to differentiate quantity at a purely visual level, and instead learned best through the tactile: something about physically touching different objects resonated with her in a way that the flatness or undifferentiated nature of the iPad’s screen did not. In this way, the researcher hypothesizes Ann created her own learning accommodations, a significant feat for any learner, especially a preschool one.

Ann liked to trace numbers on both the ToDo math app and Montessori Numbers app. She traced the written symbols and used the signifiers that gave directions on how to write the numbers. She practiced tracing the numbers over and over with each tracing task; the app would pronounce the written symbol after she traced it. This gave Ann an opportunity to identify the written symbols and connect the written symbols to their verbal pronunciations. In the ToDo app, while tracing the number, the app would also show the quantity, allowing Ann to practice learning to identify the number, write the number, and learn the quantity of the number simultaneously.

In the Montessori Numbers app when ordering numbers 1-10, Ann would use the verbal pronunciation affordance to order the numbers. She was able to order 1, 2, and 3, but as the number increased, she would have to touch each number on the screen and hear the verbal pronunciation before ordering the number in the correct spots. Although she could not identify the number, the verbal pronunciation provided her with cues that allowed her to correctly order
the numbers. These verbal cues helped Ann to complete tasks correctly. This is an outstanding example of an affordance accessed by a child (captured on videotape) which afforded a correct response.

The Case of David

**Basic characteristics of David.** At the study’s onset, David was five years and three months old and, at the end of the study, he was five years and six months old. He was the second oldest in the classroom. David was a male from a Latino background, a likable child who the researcher enjoyed working with. On the first day of the sessions, David was able to independently order numbers 1-100 with amazing accuracy. He was quite competitive and motivated when playing the iPad apps (V. Smith, Personal Communication, May 16, 2018). His teacher commented that he was very affectionate and a people pleaser (M. Newman, Personal Communication, May 17, 2018). During other center times, the researcher collected pictures of David’s ability to create complete and intricate models of cities and buildings, suggesting advanced spatial skills. He highly enjoyed constructing structures with wooden and plastic blocks. While other kids would join him in making these models of houses, shops, and streets, David remained the leader of the projects.

**Academic descriptors.** Miss Newman said that, “David, he’s one of my higher kids. He’s been one of my higher kids all year round” (M. Newman, Personal Communication, May 17, 2018). However, Miss Smith, the teacher’s assistant, suggested that David was average at the beginning of the school, but his math skills had improved significantly (V. Smith, Personal Communication, May 16, 2018). The teacher commented that he loved to play on the iPad (M. Newman, Personal Communication, May 17, 2018). David’s inclusion in this research was due to his high levels of competency with both new technologies and mathematical concepts. The
researcher observed that David was strongly motivated to work with the iPad in all app sessions and normally played with her each day. The classroom assistant remarked that “if [David knew] that other students are at the same level and have a certain score, he [thought] that higher is better, so he [was] very competitive” (V. Smith, Personal Communication, May 16, 2018). The researcher observed that David was quite quick to understand addition and subtraction within 10. She noted that, at the end of the study, he could perform mental math without any manipulatives correctly. David was strongly motivated by achieving the correct answer but became discouraged after repeated failures. If David did not answer the problems correctly, he would push the iPad away with disappointment.

**Description of interactions with number sense apps.** David interacted easily with the iPad and had strong technology skills. He had no trouble navigating the manipulatives on the screen with his fingers. He also exhibited developed number sense skills. He met 78% of the standards in the ST Math program. Most of the time, he liked playing with the iPad and had a favorable attitude towards the apps and device. He was competitive with the games and classmates and liked to progress JiJi to the next level. He would remark “look I did it!” and associated getting JiJi across the obstacles with success. Thus, he enjoyed the instant feedback of the games. He was usually motivated to play and enjoyed the self-efficacy of the learning. David was selected as a participant in this study because he exhibited competency with both technology and number sense. Table 13 summarizes David’s interactions with the number sense apps.
Table 14 - David’s Interactions with Number Sense Apps from February to May.

<table>
<thead>
<tr>
<th>Apps</th>
<th>ST Math</th>
<th>ToDo Math</th>
<th>Math Shelf</th>
<th>Montessori Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>David</td>
<td>565 minutes</td>
<td>34 minutes</td>
<td>8 minutes</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Average for Participants</td>
<td>1,248 minutes</td>
<td>19 minutes</td>
<td>19 minutes</td>
<td>43 minutes</td>
</tr>
</tbody>
</table>

Pre- and post-scores. On the TEMA pre-test, David achieved a raw score of 16 with an age equivalent of four years and six months, falling into the preschool grade equivalent. He was at the 25th percentile and had a math ability score of 90. On the student activity pre-test assessment, he scored a 90%. On the TEMA post-test, he had a raw score of 22 and his age equivalency was 5.0. He did increase in grade equivalency four months. He did move in percentile rank and math ability scores from 25% to 37%. When looking at David’s math ability scores, he remained just under the mean of 100 with a score of 90 on the pre-TEMA and a 95 on the post-TEMA. On the post-test student activity assessment, he received a score of 99.9%. Although his TEMA performance reveals just-below average math abilities, David exhibited strong problem-solving, creative, and spatial skills. Classroom interactions and performance in-app suggested a keen intellect that was not adequately captured by standardized testing. The TEMA test scores reflected that David had average understanding of early mathematics ability than was observed in the classroom. Additionally, his performance was exceptional on the informal student activity assessment, and the teacher repeatedly praised him for his mathematical understanding.

ST Math progress. David completed 78% of his objectives on ST Math, with 139 school sessions and 24 home sessions. His total usage time was 1,856 minutes. He played an average of 53 minutes a week and progressed 2.2% a week. The class average for progress weekly was
1.5%. He worked in all the domains, which included counting and cardinality, operations and algebraic thinking, number and operations in base ten, geometry, and measurement and data. He completed 90% of the objectives in counting and cardinality and almost all the objectives in operations and algebraic thinking; his completion score was 70%. In number and operations in base ten, he completed 68% of the objectives. In the geometry domain, he finished 45% of the objectives, and in the measurement and data domain, he accomplished 44% of the objectives.

Table 14 documents David’s student detail report for ST Math.

<table>
<thead>
<tr>
<th>Date</th>
<th>School Sessions</th>
<th>Home Sessions</th>
<th>Syllabus Progress</th>
<th>Average Time/Week</th>
<th>Average Progress/Week</th>
<th>Total Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/20/18</td>
<td>71</td>
<td>17</td>
<td>56%</td>
<td>57 min</td>
<td>2.5%</td>
<td>1,291 min</td>
</tr>
<tr>
<td>5/21/18</td>
<td>138</td>
<td>24</td>
<td>78%</td>
<td>53 min</td>
<td>2.2%</td>
<td>1,856 min</td>
</tr>
<tr>
<td>Class</td>
<td>116</td>
<td>17</td>
<td>52%</td>
<td>59 min</td>
<td>1.5%</td>
<td>2,051 min</td>
</tr>
</tbody>
</table>

**Technology descriptors.** His parents described themselves and David as being able to learn technology easily. They reported that he played with technology approximately 3 hours a day at school, home and in the car. They assisted him when playing with technology and encouraged him to use technology (Parent Survey 1,2,3,4,8, and 9). The researcher observed that he could turn on and off the iPad, easily navigate between and within apps, and adjust the volume. Additionally, he had no problem logging into ST Math. He could normally complete his 10-minute sessions.

**Affordance descriptors.** When working on understanding addition and subtraction to 10, David specifically would count the red shoes to acquire the correct combination of legs on the characters. He did this with greater speed and accuracy compared to other students in his class. It
was as if he knew the answer automatically and without much thought. When ordering the numbers 1-100, David would take advantage of the speech to text feature on the app to ensure he ordered higher numbers correctly. He had strong hand-eye coordination and could easily move the manipulatives on the screen to complete the math tasks. He enjoyed the individualized activities that were at his grade level or above. If something was too easy or too hard he did not want to play, so the apps afforded him individualized learning.

At the end of the study, David performed at a kindergarten level in mathematics according to the TEMA. He illustrated his mathematics ability on a game called number balance within the ToDo math app wherein he added numbers without any quantity representation. The game consisted of a balancing scale; for example, on one side of the scale might be 3 + ?, and on the other side of the scale would be 4. David would have to find the number that replaces the ? by selecting the correct number. When he did so, the scales would balance out. If he selected the incorrect number, the balance of the scales would not be equal. He used this affordance of the balancing scale as he moved forward in the game. The problems within the game increased in difficulty; for example, it would provide on one side of the scale ? + 4 and on the other side of the scale 3 + 2. David then had to select the correct number for the ?. He used the visual display of the balancing scale to answer these questions. He was the only preschooler in the group who added numbers without quantity representation, a significant accomplishment for a preschooler. He did this with accuracy and speed, and accomplished three levels in a short time.

The Case of Chase

**Basic characteristics of Chase.** Chase was a Hispanic male who was five years and four months old when the research project started and was five years and seven months old when the project ended, the oldest child in the class. The teacher described Chase’s personality as “dour.”
She went on to say that he looked at life as “glass half empty” (M. Newman, Personal Communication, May 17, 2018). According to the teacher, Chase was hard to motivate and, as a strategy, she paired him with peers he liked. If he collaborated with friends, he was more motivated to engage in the activities. Chase was more positive when interacting with other students he enjoyed (M. Newman, Personal Communication, May 17, 2018) and would normally follow directions without resistance (V. Smith, Personal Communication, May 16, 2018). In a group setting, Chase’s personality was unassuming and ordinary; he was not necessarily the child who “stood out” among his peers.

**Academic descriptors.** The teacher called him “fairly average,” and reported that Chase was performing at a preschool academic level. She described him as being very low at the beginning of the school year, however he was average for the study’s duration and adequately met the standards that were expected for preschool (M. Newman, Personal Communication, May 17, 2018). The teacher’s aide commented that he was an easy-going child who was in the middle of the class academically. She remarked that he still had objectives he needed to learn, but he was on the right path (V. Smith, Personal Communication, May 16, 2018). Chase was purposefully selected for inclusion in this research due to the consistently average nature of his performance academically.

**Description of interactions with number sense apps.** Chase’s level of engagement with the iPad and mathematics apps varied daily. Often, the researcher would have to constantly encourage him to do the next step in solving the problem. He was not competitive with the game or other students. He had trouble moving the manipulatives on screen at first, but by the end of the school year, was usually successful with his touch counts. He created his own sound effects to the game to keep himself entertained, making his learning more closely resemble play. He
became bored easily and frequently did not want to continue playing the game. He did not seem to care about his success or JiJi’s progress. He would just walk away from the iPad if he did not want to interact with the iPad anymore.

Table 15 summarizes Chase’s total interaction time with the 4 apps used.

Table 16 - Chase’s Interactions with Number Sense Apps from February to May.

<table>
<thead>
<tr>
<th>Apps</th>
<th>ST Math</th>
<th>ToDo Math</th>
<th>Math Shelf</th>
<th>Montessori Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chase</td>
<td>962 minutes</td>
<td>22 minutes</td>
<td>8 minutes</td>
<td>38 minutes</td>
</tr>
<tr>
<td>Average for Participants</td>
<td>1,248 minutes</td>
<td>19 minutes</td>
<td>19 minutes</td>
<td>43 minutes</td>
</tr>
</tbody>
</table>

Pre- and post-scores. On the pre-test TEMA, Chase’s scores reflected that he was one percentile and preforming at a preschool level. He had a math ability score of 65, two standard deviations below the mean of 100 according to the TEMA normative scale. At the beginning of the study he had an age equivalent score of 3.3 years, at the end he had an age equivalent of 4.6. On the post-test TEMA, he scored at the 16th percentile with a math ability score of 85. His math ability score in the beginning reflected that he was two standard deviations below the mean by the study’s close he was only one standard deviation below the mean. His age equivalency score was 4.6 years, which was still at a preschool grade level. His raw score on the pre-TEMA was a 4 and on the post-TEMA it increased to 16. On the pre-student activity, he scored a 30% and on the post-student activity sheet he scored 70%. Table 16 covers Chase’s ST Math student detail reports.

ST Math progress. Chase accomplished thirty-seven percent of ST Math’s outlined objectives. Chase struggled with the transition involved with groupings of ten and needed to
repeat the “alien capture” game at least eight times. Compared to other participants in this study, Chase’s ST Math achievement was below average.

Table 17 - ST Math Student Detail Report for Chase from February to May.

<table>
<thead>
<tr>
<th>Date</th>
<th>School Sessions</th>
<th>Home Sessions</th>
<th>Syllabus Progress</th>
<th>Average Time/Week</th>
<th>Average Progress/Week</th>
<th>Total Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/20/18</td>
<td>69</td>
<td>4</td>
<td>22%</td>
<td>55 min</td>
<td>0.9%</td>
<td>1,244 min</td>
</tr>
<tr>
<td>5/21/18</td>
<td>134</td>
<td>4</td>
<td>37%</td>
<td>63 min</td>
<td>1%</td>
<td>2,206 min</td>
</tr>
<tr>
<td>Class</td>
<td>116</td>
<td>17</td>
<td>52%</td>
<td>59 min</td>
<td>1.5%</td>
<td>2,051 min</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Technology descriptors. The teacher’s aide stated that Chase had limited access to the iPad before preschool. He did not use it in the home setting. She explained that using the iPad in class was his first experience with the touch count interfacing that the iPad offered. His touching and maneuvering of the mathematical manipulatives was hindered at first by his lack of experience. However, as the year progressed, he quickly learned the necessary skills to successfully navigate the technological device and enjoyed it (M. Newman, Personal Communication, May 17, 2018). Because Chase was sometimes stubbornly unmotivated to work, distinguishing his relative technology skills could be challenging. His parents reported that he used some technology at home to learn preschool concepts (Parent Survey Question 9). The ST Math detail student report indicated Chase had only 4 home school session, the lowest of any participating student in the study.

Affordance descriptors. In addition, and subtraction tasks up to five, when using birds to represent quantity, Chase would touch and count the birds. This touching and counting of birds provided an affordance of representation of number. As he touched and counted the birds on the wire, the birds would change colors. Then, he would have to look at the number operation,
for example 5 -3, to know if he needed to take away or add birds. He was not completely sure about the operation to be performed with the birds and often needed help. He seemed to be still learning the subtraction and addition signs. The researcher observed that the visual of the birds flying away fostered the understanding of subtraction. Additionally, adding birds to the wire supported the learning of addition. However, Chase sometime used concrete materials in addition to the objects on the screen when practicing addition and subtraction problems.

The Case of Jay

**Basic characteristics of Jay.** Jay is a Hispanic and Asian male who was five years three months old at the study’s beginning and five years six months at its close. He was the third oldest among the participants. The researcher observed that Jay was reserved, quiet, and obedient. He consistently followed teachers’ directions and frequently participated in small and larger groups activities. He was a child who loved to learn and was fiercely independent. He was more mature than most of his classmates and easily and successfully approached independent activities (F. Day, Personal Communication, May 17, 2018). He was motivated by correct answers (F. Day, Personal Communication, May 17, 2018) and possessed a striking level of self-motivation and independence. Jay did not require prodding or encouragement from others, whether teachers, classmates, or the researcher. Jay could work independently for long, uninterrupted periods of time; in one video recording of iPad sessions, the researcher documented Jay working independently for a solid half hour.

**Academic descriptors.** Miss Day commented that Jay was one of the higher kids, mostly because he learned quickly (F. Day, Personal Communication, May 17, 2018). He participated in class discussion and liked to be the first one to answer. He always wanted to answer questions correctly (F. Day, Personal Communication, May 17, 2018). Miss Jones, the teacher’s assistant
stated “he [had] the ability to work independently very successfully” (M. Jones, Personal Communication, May 17, 2018). She continued: “you [could] give him a single set of instructions and he [would] just run through it” (M. Jones, Personal Communication, May 17, 2018). If he did not understand or answered the problem wrong, he would not ask for assistance; instead, he simply continued working. The researcher concluded that Jay had strong problem-solving and critical thinking abilities for his age. The teacher described him as having one of the highest skill levels overall in mathematics, literacy, writing, self-help skills, and social skills (F. Day, Personal Communication, May 17, 2018). She went to say Jay was the highest one in the higher group (F. Day, Personal Communication, May 17, 2018).

**Description of interactions with number sense apps.** Jay interacted with the iPad proficiently. He was observed working independently for up to 30 minutes at a time. The iPad was a useful tool for Jay because he could work at his own pace without any assistance from teachers, aides, or classmates. He demonstrated exemplary technology and mathematical abilities. He had an enthusiastic and favorable attitude about working on the iPad and never refused to play apps. He enjoyed achieving the correct answer when playing ST Math’s software. He related success with the app’s beep and JiJi crossing the screen. He was always motivated to progress JiJi to the next level. On ST Math, in the domain of counting and cardinality, he met 94% of his objectives. In the domain of operations and algebraic thinking, he achieved 95%. He also did well in both the geometry and measurement and data domains with a 90% and 98%. The only weakness Jay showed was in number and operations in base ten when dealing with addition and subtraction. Table 17 summarizes Jay’s total interaction time with the 4 apps used.
Table 18 - Jay’s Interactions with Number Sense Apps from February to May.

<table>
<thead>
<tr>
<th>Apps</th>
<th>ST Math</th>
<th>ToDo Math</th>
<th>Math Shelf</th>
<th>Montessori Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jay</td>
<td>1,061 min</td>
<td>9 min</td>
<td>14 min</td>
<td>15 min</td>
</tr>
<tr>
<td>Average for Participants</td>
<td>1,248 min</td>
<td>19 min</td>
<td>19 min</td>
<td>43 min</td>
</tr>
</tbody>
</table>

Pre- and post-scores. The most conspicuous thing about Jay’s performance was that he progressed from a pre-test raw score of 8 to a post-test raw score of 33 on the TEMA. He was in the third percentile on the pre-test TEMA and, at the end of the study, he was in the 79th percentile. This is remarkable. He progressed in leaps and bounds during the 3.5 months of study. His math ability score went from a 72 to 112, moving from nearly two standard deviations below the mean to almost one standard deviations above the mean. His age equivalent went from 3.9 years to greater than 6 years. Jay made the most progress of anyone in the study.

ST Math progress. Jay completed 98% of the syllabus objectives within ST Math. He accomplished the goals set for mastery in the counting and cardinality, operations and algebraic thinking, geometry, and the measurement and data sections. He did not achieve the goal set for the number and operations in base ten domain. He successfully completed 19 of the 25 objectives assigned with a 100%. Jay received 100% on the numbers and objects to 5, subitizing, numbers and objects to 10, greater than, less than, and equal to, numbers and objects to 20, and the comparing numbers sections within the counting and cardinality domain. He worked these sections between 2-5 times. He completed the understanding addition and subtraction within 5, the understanding addition and subtraction within 10, making 10 and number pairs, and the addition and subtraction within 5 sections with a 100% as well. Jay completed all the objectives’ modules with 100% except the number and counting to 100 modules. The ST Math student detail
report stated that he had 105 school sessions and 5 home sessions. Jay was above the class average in number of school sessions, which was 75, but below the class average in number of home sessions, which was 17. His average time per week on the iPad apps’ games was 45 minutes. He progressed an average of 2.8% a week and had a total time of 1,532 minutes. Table 18 provides Jay’s ST Math student detail reports.

Table 19 - ST Math Student Detail Report for Jay from February to May.

<table>
<thead>
<tr>
<th>Date</th>
<th>School Sessions</th>
<th>Home Sessions</th>
<th>Syllabus Progress</th>
<th>Average Time/Week</th>
<th>Average Progress/Week</th>
<th>Total Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/20/18</td>
<td>33</td>
<td>5</td>
<td>25%</td>
<td>21 min</td>
<td>1.1%</td>
<td>471 min</td>
</tr>
<tr>
<td>5/21/18</td>
<td>105</td>
<td>5</td>
<td>98%</td>
<td>45 min</td>
<td>2.8%</td>
<td>1,532 min</td>
</tr>
<tr>
<td>Class Average</td>
<td>75</td>
<td>17</td>
<td>60%</td>
<td>65 min</td>
<td>2%</td>
<td>1,849 min</td>
</tr>
</tbody>
</table>

Technology descriptors. Jay’s parents reported that he could solve his own technical problems, that he learned technology easily, and that he both played and knew a lot about technologies (Parent questionnaire question 3). They reported that he played on the iPad outside of school for about two hours daily on average. His parents both encouraged and assisted Jay when he used technology. They reported that he played technology in the car, at home, while traveling, at friends’ or relatives’ houses, in restaurants, and at school. He could perform a variety of activities on the iPad such as takings pictures or selfies, listening to music, and watching educational and entertainment cartoons, videos, and games. He even knew how to communicate with family and friends on Skype, Facetime, and the phone (Parent questionnaire question 13). The researcher noted that Jay could turn the iPad on and off, navigate within and between apps, and adjust the volume. He could quickly understand tasks and activities on the apps. He had no problems with the technology and seldom asked for assistance.
**Affordance descriptors.** Jay exhibited a strong desire to get the correct answers. This is extremely prominent in his work on the ST Math software. Videotaping captured him expressing excitement when he accurately completed the tasks and puzzles. Such phrases as “I get it,” “wow,” “yeah!” and “I did it!” were frequently voiced by Jay as he accomplished progressive levels in each module. He attended to the instant feedback of a beep within the ST Math app that notified him that he correctly answered the problems. This was an affordance for Jay that kept him on-task and encouraged him to continue playing. The teacher’s aide commented that he liked to get answers right, and listened for the beep. She went on to express that he persisted until he comprehended the mathematical concepts presented (M. Jones, Personal Communication, May 17, 2018).

Another affordance related to achievement that was evident with Jay and no other child was that he knew that the two JiJi characters at the bottom of the screen represented how many problems he could get wrong and still progress to the next level. He cued into this display, observing it with each game he played as a marker to advancing to the next level. Additionally, he was prompted by the percentage bar at the bottom of the page that told him what percentage of problems he had correctly answered. Jay realized that, for mastery, he needed between 80-100%. The researcher noted that he would sometimes want to play the game over to get 100% before moving to the next level. These affordances regarding accuracy were understood and accessed by Jay.

Jay had superior number sense, and he operated the touch screen device proficiently. He attended to the visual cues of ST Math’s software and seemed to intuitively understand concepts of addition. In the visual number bouncing shoes scenario of the game, he accessed the visual displays with trouble-free critical thinking skills. In this scenario, different amounts of red shoes
were exhibited and there were visual characters with different numbers of legs. Jay would consistently count shoes and then select the characters with the correct number of legs. This exercise was a building block for a more advanced level of addition and subtraction without visual representations as cues.

Jay began to memorize the characters and how many legs each character had. For example, a lamp had one leg, the ostrich had two legs, the robot had three legs, the dog had four legs, the star had five points, the ant had six legs, the green insect had seven legs, the octopus had eight legs, the school bus had nine legs, and the lobster had ten legs. When he worked the problems, Jay would first count the number of red shoes provided by the app. For instance, six red shoes would appear onscreen, then Jay would count the red shoes and select the character (or characters) with the correct number of legs. Thus, for six red shoes, he would select the ant with six legs, or the dog with four legs and the ostrich with two legs, or the star with five points and the lamp with one leg. As he progressed though the levels, he became faster and more proficient in choosing the characters. However, in the beginning, one affordance that helped him was that, as he selected the characters and pulled them down to the shoes, the shoes would animatedly appear on the characters’ legs. This allowed him to see how many more legs he needed or give him visual cues of addition.

On the alien capture game, Jay was able to count numbers 11-20 with less effort than his classmates. The alien capture module showed little alien people in two ten frames and then dispersed them into one unit counts. For example, the number 14 would be a group of 10 aliens in one ten frame and 4 aliens in another ten frame. Then, Jay would select the number fourteen without hesitation because he knew 10 plus 4 was 14. The game also did this task in reverse by giving 16 aliens in the units of ones and then grouping 10 of them in a ten frame and putting the
remaining six in a ten frame for the child to select 16. This afforded Jay to automatically know the number 14 or 16 without counting. Other children did not access the affordance of grouping the first 10 aliens, but Jay used the affordance without problem, maintaining both accuracy and speed. In general, Jay accessed affordances in more difficult problem-solving tasks and when related to answer accuracy.

Researcher Reflections on Parent Questionnaires

In all, there were thirteen student participants, and, out of those, twelve completed parent questionnaires were returned. Appendix U depicts the collected data. The questionnaires revealed that young students use the iPad at home and at school frequently. Parents fostered the use of technology for learning and regularly assisted their children in this exploration. This conclusion is supported by the literature, which argues that technology is becoming ubiquitous in our world. Even though these children are in preschool, the questionnaire illustrated that students are skilled with and can perform a variety of tasks on the technologies. As suggested by the previously-discussed literature in the technology focus section of this dissertation, the iPad’s portability can be an enhancement for learning. This was confirmed by the research. For example, parents reported that their children used the iPad in several different settings, including at home, in school, and on the go. Parent’s attitudes both encouraged and supported technology integration for learning.

Artifacts

Artifacts were collected in three main ways: lesson plans, pictures, and pictures of student work. The following will provide relevant details on each kind of artifact collected.

Lesson plans. Seventy-two lesson plans were collected from 5 February to 22 May 2018. The information in this section was acquired from these artifacts. The teachers’ lesson plans
were created with planbook.com. The lesson plans included instruction for the entire preschool day. They contained instruction plans for areas such as art, building habitats, dramatic play, instructional learning time, reading aloud, literacy, writing, large groups, and mathematics. The lesson plans were well-organized, and they provided details on objectives and standards, lesson instructions, materials, resources, technology use, differentiations, accommodations, and notes and reflections on lessons. For this research, the math lessons were analyzed; summaries are included below. These lessons gave rich descriptions of daily activities and tasks that preschoolers complete.

The following are standards that were covered in the class in addition to ST Math objective in the mathematics software:

- 1.PK. 5 Use concrete objects to combine and separate group up to 5.
- 1.PK.3a Recognize and read numerals 0-5.
- 1.PK.3b Estimate the number of objects in a set of 5 and verify by counting
- 1.PK.3c Match the number of objects in a set to the correct numeral 0 to 5
- 1.PK.4a Count to 10.
- 1.PK.4b Count to 10 by demonstrating one to one correspondence using objects.
- 1PK 5 use concrete objects to combine and separate groups up to 5
- 2.PK.1 Sort objects by similar attributes (size, shape, and color).
- 2.PK.2 Recognize and replicate simple patterns
- 2.PK.3 Compare sets of objects. Determine which set has more or less.
- 3.PK.1 Compare objects by size to determine smaller and larger.
- 4.PK.1a Identify circles, triangles, and squares
- 4.PK. 1b Begin to recognize two and three-dimensional shapes in the environment.
4.PK.2 Identify positions (front, behind, next to, up, down, inside, on top, ordinal positions)

5.PK.1 Identify and sort information (interpret quantity in pictures).

Counting forward and backward to 10

Addition and subtraction

Measure length of objects

Compare amounts

Daily small group activities in mathematics focused on a variety of number sense components such as counting, listing and counting, counting forward and backward, ordering, matching numeral to amount, comparing numbers, comparing amounts, and comparing and ordering numbers. In the subject of geometry, lessons emphasized making shapes, distinguishing shapes, sorting shapes, looking at shapes and patterns, finding attributes of shapes, and learning 2- and 3-dimensional shapes. Students also learned about measurement by studying the length and height of objects. Students learned small, medium, and large, and measured long and short objects in lessons that focused on longer, shorter, and the same. Additionally, measurement focused on more, less, fewer, shorter, longer, taller, lighter, and heavier. Furthermore, teachers employed simple word problems for addition and subtraction.

The lesson plans provided instructional questions that were posed to students in group activities. The following is a summary of the emphasized questions:

- How many is that altogether?
- How many more (or less are there?)
- What number is this?
• How many do we have altogether?
• How do you know that’s a (triangle)? Identify the key attributes of each shape.
• Which shape did you see?
• How many spaces did you hop?
• What number did you land on?
• Which set has more/less?
• How many more/less?
• Which tower is bigger/longer?
• Which card has one more dot?
• Which card has one less dot?
• Which card has more/fewer dots?
• Which card has two more dots?
• Which card has one less dot?
• What is the missing number?
• How many do it I have?

The teachers used a variety of manipulatives for students to learn mathematics, such as:
• Number cards
• Linking cubes
• Crayons
• Fingers
• Shape manipulatives
• Art supplies
• Counters
• Measuring tools
• Paper plates
• Numeral dot cards 1-10
• 2 dimensional shapes
• 3 dimensional shapes
• Cone, Cube, Cylinder, and Sphere
• City skyline photos
• Dry erase board
• Dice
• Marbles
• Boxes
• Domino cards
• Bags
• Classroom objects
• Small toys
• Counting Cubes
• Counting cards with pictures

Different types of instruction were used to teach mathematics according to the lesson plans. For example, storybooks were often implemented in small groups. *Six Little Ducks* was used and, on different pages in the book, students counted down until only one duck remained. Duck pictures were lined up in a row to six, and children pointed to the duck that was first and so
on. This math literature lesson instructed counting to 10 by demonstrating one-to-one correspondence and by using duck images. Other math literature books were used throughout the school year.

Kinesthetic instruction was also used in small group activities; for example, a number was stated or shown on a number card. The children would then, jump, spin, or wave their arms the correct number of times as they counted out loud for numbers 1-30. Additionally, instructional videos projected on a large screen were used and children followed dance movements as they counted. There were a variety of different videos used in this manner to facilitate learning through movement. Another kinesthetic exercise, teachers used was having students line up and asking students, who is first? second? and so on.

Another strategy used in the preschool classroom to teach number sense was through finger play and songs. “1, 2, Buckle My Shoe,” “This Old Man,” “Five Fat Turkeys,” “Ten in a Bed,” and “Five Little Monkeys” were the class favorites. Teachers used mathematics manipulatives as resources for students to learn one-to-one correspondence and addition. As another example, preschoolers were given an empty box. Then, they were instructed to fill the box with a designated number of objects. The teacher guided the children to count the correct number as they placed the objects in the box. These problems were easily adapted to simple addition and subtraction tasks. The researcher concluded that the teachers used best practices and demonstrated effective instructional strategies for the preschool children to learn mathematics in addition to using the ST Math software.

**Pictures.** A total of 171 pictures were taken to document mathematical learning and the students’ use of manipulatives. These pictures captured different manipulatives and activities used in the mathematics learning centers. The following highlights some of the most interesting
activities and manipulatives. There was an assortment of counters used in the preschool classroom, such as toy bear counters, animal counters, airplane counters, and dinosaur counters. These are just plastic manipulatives in different shapes for children to practice counting. There were a variety of materials that connected the symbol of the number to its representation. For example, there was a counting car activity in which cars were labeled with a written number and then the students had to put the correct number of plastic toy people in the cars. Another activity consisted of elephant cards with different numbers written on them; the student had to connect the correct number of chain links to make the elephant’s trunk. Additionally, there were rubbing template tasks in which the student used the template to create a rubbing of the number and an amount using crayons and paper. Construction of number art was also employed; in this activity, a number was disassembled into shapes and students had to reconstruct the number with the shapes.

**Student work.** The pictures documented student work and gave visuals to creative fun teaching activities. There were all kinds of activities designed around identifying numbers. The following were the most interesting of student work collected. Students made the number four with smiley face stickers and created the number two with feathers. Images and activities were recorded for the 100th day of school. One teacher had students create a worm with 10 circles and within each circle was 10 dots. Another teacher had students create structures with 100 red cups. Additionally, students constructed “100 days smarter” king and queen crowns. On that day, each student, at snack time, created a hundred chart with snacks such as cheerios, fish crackers, and different types of snacks. Student work was collected regarding the book *Fox in Socks* by Dr. Seuss in which different colored socks were counted and then the teacher developed a visual pictograph utilizing these different colored socks. In another lesson focusing on data, the teacher
asked students “what mode of transportation did you use to get to school?” She then took the collected data and created a pictograph using cars, buses, bikes, and a person walking.

Student Semi-Structured Interviews

The student interviews were limited in rich detail due to the children’s ages. Participant ages ranged from four years and eight months to five years and five months. In general, the young students did not articulate in-depth responses. The duration of participant interviews ranged from 1 minute and 37 seconds to four minutes and 44 seconds. There was a total of 13 children interviewed. The higher-level students seemed to be able to express their thoughts about the apps more fluently.

It can be concluded that all students liked and played with the iPads (Personal Communication May 22, 2018). When asked “What do you like about the iPad?” students answered: “I like to play the games” or “when it shows me stuff” (Jay, Personal Communication, May 22, 2018), “it is really fun” (David, Personal Communication, May 22, 2018 ), “that I can keep playing it” (Dana, Personal Communication, May 2018), and “because I can play games” (Andy, Personal Communication, May 22, 2018).

Most children reported that they interacted with apps in school and at home. Some students reported that their parents helped them when they played JiJi at home (Mike, Personal Communication, May 22, 2018 Ann, Personal Communication, May 22, 2018). When asked “What do you find helpful about ST Math?” one student stated, “when I get on it and I don’t know what to do it help me” (Mike, Personal Communication, May 22, 2018). Another student said, “when it shows me the stuff” (Jay, Personal Communication, May 22, 2018). When asked “What is your favorite feature of the app?” A student stated “when JiJi, when JiJi climbs the ladder” (Alex, Personal Communication, May 22, 2018).
Most students gave favorable answers regarding features such as voice, direction, musical cues, movable manipulatives on the screen, and counting practice games. The majority of the students said they liked the instant feedback that the app provided for correct or incorrect answers. Nearly everyone expressed a positive learning experience when using ST Math and the other number sense apps.

Affordances

The following patterns and themes emerged after reviewing nearly 33 hours of captured interactions with 6 participating preschool students. Since affordances accessed and student ability corresponded and occurred in relation to one another, it should be stated that participants in this study had a wide range of mathematics ability and, therefore, each child accessed different affordances. An affordance for one preschooeler may not have been an affordance for another. The researcher concluded that, often, affordances in apps can support learning and performance for one student but have an effect on the performance of another student. Additionally, there were affordances that hindered or slowed down the learning performance for some students, but other students adjusted quickly. The hindering affordances were referred to as constraints in this study. Sometimes, an affordance could also be ignored by the preschooler. Through observation alone, the research coders could not clearly determine whether a child did not notice an affordance or if the preschooler elected to ignore the affordance.

Replaying video data permitted researchers to frequently return to the tapes to find overall patterns in interactions and affordances accessed. In addition, the coders denoted constraints that limited potential structures for action. Video data allowed the research coders to watch participants’ interactions with the apps repeatedly and in separate viewings. By doing so, researchers were able to provide holistic details on children’s interaction with the app. Each
chosen participant had between 4 -7 hours of videotaped interactions with the different apps. This rich video analysis afforded context for the research. Table 19 includes students’ video-recorded hours and total minutes spent on ST Math.

Table 20 - Students’ Video-recorded Hours and Total Minutes on Apps.

<table>
<thead>
<tr>
<th>Student</th>
<th>Video hours recorded</th>
<th>Total Minutes on Apps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mike</td>
<td>7 hours 25 minutes 53 seconds</td>
<td>2,086 minutes</td>
</tr>
<tr>
<td>Dana</td>
<td>6 hours 10 minutes 7 seconds</td>
<td>2,362 minutes</td>
</tr>
<tr>
<td>Ann</td>
<td>4 hours 25 minutes 85 seconds</td>
<td>761 minutes</td>
</tr>
<tr>
<td>David</td>
<td>4 hours 16 minutes 23 seconds</td>
<td>637 minutes</td>
</tr>
<tr>
<td>Chase</td>
<td>3 hours 16 minutes 37 seconds</td>
<td>1,030 minutes</td>
</tr>
<tr>
<td>Jay</td>
<td>7 hours 52 minutes 43 seconds</td>
<td>1,099 minutes</td>
</tr>
</tbody>
</table>

**Affordances accessed.** The most frequently occurring affordance across apps was the visualization of a touch count when practicing counting. This visualization varied slightly amongst apps, but always included some type of immediate sensory feedback to correspond with touch counts, such as objects changing color when touched, moving or shaking in response to touch, or audio cues (beeps, music) in response to touch.

Preschoolers who advanced through ST Math’s modules (and progressed similarly in other apps utilized) learned the tasks within the different JiJi scenarios and used accurate touch count interactions when playing with the touch screen games.

Higher academically performing preschoolers keyed into the app’s immediate feedback more often to validate their reasoning to enable their advancements to the next level.

Lower academically performing preschoolers keyed into the app’s immediate feedback more often to permit self-correction.

Preschoolers who accessed affordances tended to improve in accuracy.
Higher academically performing preschoolers were able to access the affordance of representation of quantity by understanding that a grouping of ten ones visually represented an unchanging unit of 10. This allowed them to learn numbers 10-20 on the app more quickly and accurately.

Lower academically performing preschoolers did not grasp the idea that ten ones became an unchanging unit of 10. Without the ability to access this affordance of representation of quantity, these participants were slower to learn numbers 10-20 and with less accuracy. Furthermore, because these participants continued to rely on individually counting objects to ten, the app’s prompts became tedious for this group.

The affordance of verbal pronunciation of numbers helped preschoolers order and identify numbers more accurately.

The affordance of representation of quantity connected to written symbol aided in the preschoolers’ learning.

The affordance allowing preschoolers to recognize an incorrect response afforded better accuracy in proceeding attempts.

A motivational aspect for learning within the educational game-based apps was afforded by providing tiered, accomplishment-based progress. In ST Math, this progress was represented by the app’s mascot, JiJi, who traversed terrain in response to student achievement. In ToDo Math, student achievement was reflected in a progress-based path leading to greater heights.

Lower academically achieving students benefited by working with concrete manipulatives in addition to visual affordances provided within the educational game-based apps.
Lower academically achieving students benefited by collaborating with others in addition to provided affordances.

Constraints

For the purposes of this study, constraints are considered in-app restrictions on possible user actions. The constraint provides structure for action; in general, the researcher considered constraints to be hindering visual cues. Constraints were identifiable and consistent throughout ST Math’s games; the focus on ST Math is due to participating teacher preferences and its more regular integration into participating classrooms. Patterns emerged from the video interactions captured during the study’s 14-week duration. For most students, the most frequently occurring constraint was the size and visibility of on-screen images, including the size of the pictures, diagrams, virtual manipulatives, number images, ten frames, and number lines. Overall, the researcher would urge educational app game designers to construct bigger displays, so children can more easily count and interact with the digital touch screen visuals. The small size of the displays restricted counting accuracy. The researcher noted that all participants, no matter their number sense or technological ability, encountered difficulty in this area. Even the very highest achievers expressed frustration at first when interacting with the small displays. The following paragraphs will identify the most frequently observed constraints gathered from the videotapes.

**Number sticks.** In the domain of counting and cardinality within ST Math, the number stick games were levels within the “counting objects to 10” objective. Different scenarios were provided for the student to learn numbers 1-10. For example, the numeral 7 appeared on the screen. Then, the symbol was animated and turned into 7 sticks in the shape of the numeral 7. The number stick games afforded the child opportunities to connect a written symbol to a quantity representation or vice versa. The constraint here was that the sticks needed to be larger,
so the child could more easily touch and, thus, count the sticks. The sticks were visually too close together when forming the numbers to be identified. All students exhibited difficulty at first when trying to count the sticks. Some students did not have adequate hand-eye coordination to touch the small number stick figures. Students who progressed were able to overcome the small sticks and correctly identify the numbers. Although the sticks provided structure for counting quantity, the size of the visual cues made it difficult for some students. Struggling students had to play this game between 14-36 times to complete the module in ST Math. Stronger students still had to attempt this game 4-6 times to successfully complete the module.

Figure 9, below, depicts the stick games.

![Figure 9 - Screenshots of number sticks.](image_url)

**How many legs.** In this task, students were asked to count the number of legs on different characters and select the correct number of shoes for the corresponding legs. Once again, different scenarios were used as the student progressed through the module. The constraint here was that the characters needed to be significantly larger on the screen, so the children could more easily count their legs. Additionally, there needed to be more space between each leg. For
example, the lobster character had ten legs; the students struggled to count its 10 small legs. The child’s fingers were bigger than the legs displayed on the screen; therefore, they would often not count all the legs correctly. The researcher purchased stylus pens to help students overcome this constraint if students found it useful. These characters were a base visual for addition and creating pairs of 10. Because ST Math utilizes the affordance of recurring, familiar characters, these many-small-legged characters appeared and reappeared throughout the game’s levels. In this way, these recurring characters became a constraint because students continued to encounter difficulty in counting their legs. Only the top two participants were able to complete all the levels that used the “how many legs” scenarios. Figure 10 illustrates the small illustrations the children had to count.
Ten frame display. Ten frames were used to help students learn numbers 1-20. The ten frame dimensions were tiny with respect to the screen. Students would touch a box to count it, visualized by the box filling with color, and their touch count would fill in two boxes. This sometimes left the child feeling aggravated. The researcher noted that students would express frustration at this occurrence. If the ten-frame display was just a bit larger, the visual manipulative would have improved student interaction. The display hindered correct touch counts and restricted choice.

Additionally, when students were asked to display the number 11 on the ten frames, they would touch and color in all the boxes in the first ten frame. Then, the student must hit the left
side bottom box of the second ten frame to display the 11 correctly. If the child selected the right-side bottom box (or any other box in the second ten frame), the representation would be the number 16 (or another incorrect response). This restricted accuracy in representation and seemed to impact the lower number sense students the most. The research would suggest that educational app developers consider allowing students to choose any box in the second ten frame to create 11; ultimately, the design of this particular in-app game should consider less rigidity in ten frame box value. Figure 10 is the ten frames.

![Figure 10 - Ten frame display.](image)

**More, less, or equal to parachute unstacked.** In this game, JiJi wore a parachute and the student must stack vertical boxes in amounts less than, more than, or equal to another stack of boxes. Correctly stacked boxes created a line enabling JiJi to parachute and land safely. There were two vertical stacks of boxes on the left and right of the screen. The symbols for equal to, greater than, and less than were individually reproduced at the end of the line. One side of the
boxes were colored in and the child must color in the boxes on the other side according to the less than, more than, or equal to symbol displayed. The display had a large number of different working parts for the child to consider: the left and right stacks of boxes as well as the line, which moved depending on the selected and colored in boxes. There were too many visuals in this game and the objective was not apparent to the participant, meaning students did not know what to look for. A simpler display would work more effectively for students to learn the less than, greater than, and equal to concepts. The cues and displays were too intricate and caused confusion for the children. In this way, a convoluted design posed an obstacle to learning the concepts of less than, greater than, and equal to. Only the high achieving students were able to successfully accomplish this section and overcome these constraints in design and display.

Another constraint with this game was that its visualizations of less than, greater than, and equal to signs were extremely small on the line. The students had a hard time finding the less than, greater than, or equal signs because they were placed in the corner of the moving line and were not consistently visible onscreen. This awkward placement onscreen caused confusion amongst participants. The preschoolers struggled to understand what steps were needed to correctly compete the task; in this way, the game’s objective was not immediately clear. Thus, technological and understanding complications superseded student learning. Lower achieving students could not pass levels without assistance that bordered on teacher execution of the level’s tasks and higher achieving students had to play the game 2-5 time for mastery. Figure 11 depicts the More, Less, or Equal to Parachute Unstacked game.
There was a game in ToDo Math called “feeding time” that worked on the same mathematical concepts of less than, greater than, or equal to with a simpler game display. In this game, there was an alligator and students were shown two numbers to the left and right of the alligator. Big symbols for less than, greater than, and equal to were displayed beneath the alligator to prompt students to select the appropriate symbol. After successful selection, the alligator would eat the number, the mouth of the alligator animating into a less than, greater than,
or equal to sign. Students were much more successful in completing this game due to its simple display, intuitive interface, and more readily discernible objective. Figure 12 depicts the feeding time game on the ToDo app.

![Feeding Time Game on ToDo App](image)

**Figure 12** - Depicts the feeding time game on the ToDo app.

**Figure 13** - Screenshots of “feeding time” on ToDo Math.

**Geometry sections.** There were a few constraints within the geometry domain observed in the composing shapes and position modules. Only the two highest achieving students in the study advanced to these modules. In the “position rotation-upright JiJi” portion, JiJi had to be rotated in different directions to mirror the image of his figure on the right hand of the screen.
There were arrows given to let the child rotate JiJi; however, it was very confusing and often resulted in the wrong answer. In the dot shape activity, dots were too close together, making it difficult for the child to create the desired shape. Thus, it made the shapes too small and the lines difficult to drag. This constraint restricted movability and ability to drag the appropriate lines and dots within the tasks. In the composing shapes section, students were asked to compose shapes. For example, a student might be asked to create a square using two triangles. The student would select the first triangle and drag it over to the square and release it. The triangle had to be lined up with the square when the student used the click drop touch count for the triangle to fall into the square. However, it was challenging for the student to line up the triangle and successfully drop it into the correct position. This task would have worked better if the triangle was a free moving virtual manipulative. The rigidity of what qualified as a “correct” response created an imposition to student progress; although participants understood the concepts, the constraint of dragging and releasing resulted in numerous unsuccessful attempts.

Researcher Reflection on Constraints

Even though there were some constraints in the ST Math software, students were provided with a digital educational tool that fostered and increased mathematical understanding and skill. All students in the study showed growth in their mathematical ability. The researcher would urge preschool-aged educational game-based app designers to make displays on the screen as large as possible to allow unrestricted interactions with virtual manipulatives. Additionally, game displays should be kept simple with straightforward educational activities and puzzles that do not interrupt the learning of mathematical content.
Chapter 5: Conclusion, Discussion, Limitations, and Future Implications

Chapter 5 is devoted to the conclusion of the research study. This chapter also covers a discussion in which the cases are compared and contrasted. Then, the limitations of the study are presented. At the end of this chapter, implications for future research are considered.

Summary and Discussion

**Theoretical framework connections.** Constructivism provides a fundamental theoretical framework to the acquisition of foundational mathematics concepts. Constructivists have emphasized that children need interaction and play in order to successfully acquire these early mathematics concepts. Thus, the incorporation of mathematics concepts with game-based apps exemplifies this Constructivist approach of the necessity of play for children’s successful learning. Moreover, digital play is the first change in play in centuries; suddenly, digital play provides manipulatives that are two dimensional, occurring onscreen. This new type of play is the first radical shift in children’s playing for learning, thus it merits close observation. In 2018, play is being redefined to a certain extent in this idea that it occurs in a purely digital space. Furthermore, the multimodality of iPad technology integrates the child’s natural inclination to see, hear, and touch as they learn.

The preschoolers enjoyed playing game-based learning apps, as observed by their teachers, parents, and the researcher. The teachers commented that, when mathematics is presented in a game-like format, students do not see it as mathematics but rather as a game. This reinforces how the Constructivist theoretical framework views learning for young children. Constructivism has long noted the importance of active and free play for young learners. Constructivist principles insist that play is a critical element in children’s learning process (Hedden, Speer, Brahier, 2009). The studied number sense apps provide an individualized
educational experience that is bursting with interactive opportunities. Through app interactions, students gain mathematical concepts through play. This aligns with Griffin’s (2007) research, which identified that additional exposure to mathematics through iPad play is valuable. Action involving seeing, touching, and hearing, according to Piaget, would enhance development of schema; these actions are provided by the iPad apps (Post, 1988). The touchscreen device offers children a multimodal educational tool that permits them the opportunity for learning mathematical concepts. The app animates mathematical concepts in an entertaining approach that explores these ideas through interactive games and puzzles for young learners.

Piaget established long ago the need for children’s learning to match their intellectual capabilities (Post, 1988), noting that level of task difficulty and materials must be appropriately matched to student cognitive ability. The iPad does this automatically in its differentiated learning; higher- and lower-achieving students are able to work at a pace that suits their needs. In this study, it was evident to the researcher if the modules were too hard for the child: they would resist playing or avoid interactions with the mathematical games and puzzles. Teachers reported that the apps provided a favorable learning environment and were beneficial didactic technologies for learning foundational mathematics skills. Most children did not resist working with the apps to learn.

Dewey’s research focused on the experiences a child has when learning (Dewey, 1938) and how positive learning experiences enhance concept acquisition. Educational iPad apps, in their interactivity and ability to stimulate, motivate, and engage students, provide these positive learning experiences for children (Sperer, 2013; Henderson & Yeow, 2012; Manuguerra & Petocz, 2011). The researcher found that, most of the time, participants were willing to work on the apps and exhibited positive interactions. Of course, some days the children did not feel like
playing, but the researcher did not have any trouble obtaining the required play time with the students. Overall, the evidence collected reflects that most of the time preschoolers found working with apps a pleasant scholastic experience. The researcher determined that the iPad presented experiences for learning in both a one-to-one and collaborative small group settings. Some of the preschoolers exhibited preference for playing in groups rather than alone.

As Vygotsky argued, collaboration in the learning process is important (Hedden, Speer, & Brahier, 2009). Chase, Dana, and Ann all worked better when they had someone to play with or discuss mathematical ideas with. These children needed verbal communication to successfully complete mathematics objectives. While, at times, they did play on their own, they needed to discuss the game and concepts of the visual math to master the game’s objectives. The results of this study and other studies determined that the iPad and associated apps are another educational technology tool to employ in the classroom for young children to collaborate and share ideas concerning mathematics (Henderson & Yeow, 2012). Classroom observations exposed that 4- to 5-year-old children have meaningful conversations that stimulate and clarify understanding.

Alongside Constructivism and the educational principles of learning proffered by Piaget, Dewey, and Vygotsky, this research utilized artifact-centric activity theory as a theoretical framework for the technological aspects. The artifact-centric activity theory played out in this research when students started learning numbers 11-20. The apps offered animations and interactions that permitted students to regroup ten units of ones into one unit of ten. By grouping a set of 10 ones together, students were able to visualize the notion that 11 is composed of one unit of 10 and one. Another example might be the number 15; there would be one set of 10 and 5 ones. The apps allowed for direct and multiple touch commands that enabled rearrangement of numbers. Sometimes, students had direct interaction in the rearranging of numbers and
sometimes the app would animate the group visually for the child to watch. Based on these theoretical educational frameworks, number sense apps illuminate appropriate educational experiences for preschool learners. Figure 13 is an example of the animation of grouping 10 one units in the ST Math app.

![Figure 13](image)

**Figure 13** - Screenshots of “alien capture” game.

**Revisiting the research questions of interactions and affordances.** More so than any previous technological device, number sense apps provide a personalized educational experience. The multi-touch screen interface permits direct interaction between the child and the content.
being learned. It also promotes flexible engagement opportunities for teaching (Agostini, Di Biase, & Loregian, 2010). This can be seen in the higher academic achievers in the study. Mike and Jay had no trouble working up to thirty minutes if permitted by the researcher. Teachers remarked they worked well independently and enjoyed navigating meaning for themselves. This confirms thoughts given by (Peng et al., 2009), that mobile learning provides a unique learning experience that allows students to negotiate understanding themselves.

The iPad, in its size and portability, allows for anytime learning (Henderson & Yeow). The six students completed a total of 706 in-school sessions and 188 home sessions on the ST Math app alone. In this study, all parents reported that their children used the touch screen devices at home and in school. The students moved at their own pace and worked on objectives that corresponded to their needs and academic levels. When employing best teaching practices, the lessons must be relevant to the child’s cognitive ability. The same is true for the integration of the iPad and apps.

The participants in the study vary in academic and technological abilities; due to this, they all had different interactions and educational experiences with the number sense apps. However, there are several affordances that are evident in all of the preschoolers’ interactions with the number sense apps. Student performance was supported by representation of quantity when connected to written symbol. Affordances that allow the preschooer to realize a mistake affords better accuracy on future attempts. Another trend found in the data was accuracy improves when young children accessed affordances. Additionally, the most frequently observed affordance accessed was that of immediate feedback corresponding to touch count when counting objects onscreen. With each touch, the objects would change color, move, or make sounds. Repeatedly, this interaction provides opportunities for children to practice counting.
Here are examples of different interactions exhibited with the educational tool. Dana needed assistance working her way through JiJi’s levels and exploring mathematical concepts. She was always unsure of the math and technology but displayed a willingness to learn with the collaboration of others. Ann gained technology skill and learned to work through foundational mathematical concepts with the aid of physical manipulatives in addition to affordances offered by the number sense apps. Chase is of average academic ability, but he was not as motivated to learn from the iPad as the others. He often had to be paired with a classmate he enjoyed working with to progress in the game.

Jay was the most independent worker of the group and could play unsupervised for long periods of time without becoming off task. Mike was savvy with technology and had exceptional critical thinking skills. David exhibited accuracy, speed, and competitiveness with the number sense apps. All participating preschoolers are examples of students who were stimulated, engaged, and motivated to learn on the iPad. This has been indicated by other studies (Spencer, 2013; Henderson & Yeow, 2012, Manuguerra, & Petocz, 2011, Lin & Pwe, 2011). Mike, Jay, and David are always looking to advance JiJi to the next level or to advance in levels within other apps. These students expressed excitement when accomplishing tasks and progressing through levels. They displayed self-efficacy and a motivation regarding number knowledge denoted by Spencer (2013).

Student ability and accessed affordances occur only in relation to one another (Greeno, 1994) and are present in matched continuous systems (Chemero 2003). Each student has an individualized range of abilities which defines in what way they access the affordance that parallels their abilities (Moyer-Packenham et al. 2015). This most certainly played out in the research: in the case of the stick affordance, Ann and Dana do not access the sticks to aid in
identification of the numbers or quantity of the number. Their low number sense and lack of ability may have prevented them from accessing the affordance. However, it should be stated that by simply observing students, one cannot conclude whether they do not recognize the affordance or if they notice and elect to disregard the affordances (Moyer-Packenham et al., 2015). In Ann and Dana’s cases, the affordance is there for them to perceive, but they did not access it. On the other hand, Chase uses the sticks and counts them consistently to help him identify and understand quantity. Chase is described by teachers as being of average ability. It is observable in the videotapes and his observed interactions that he accessed the stick affordance to identify the number and link it to quantity. Mike, Jay, and David do not need to use the sticks because they already know the numbers 1-10. This is an example of how individual ability determines if and how an affordance is accessed by a student.

In the case of Ann, it was apparent that she had to have physical manipulatives when working with the virtual manipulatives to gain understanding of the number concepts being taught on various levels of ST Math. Her classroom teacher did an exceptional job of giving Ann mathematics manipulatives that helped her progress through JiJi’s levels. This supports the ideas of Carr (2012) and Aronin and Floyd (2013), who recommend using physical manipulatives in combination with the touch-screen devices may be beneficial for educational learning of mathematical concepts. In the case of Ann, it is observed through videotaping of her interactions with the apps that physical manipulatives continually assisted her in gaining number knowledge. Other students in this study used physical manipulative as well, but it was most pronounced in Ann’s interactions with the touch-sensitive device.

David’s math ability stayed relatively the same according to the TEMA, but he displayed excellent skill and progress in mathematics. At the end of the study, David was adding and
subtracting without any visual manipulatives. He had breached the ability to add and subtract with written symbol. Additionally, he could execute simple mental math problem accurately. He was the only participant who exhibited this level of knowledge.

Jay, the most independent worker and thinker of the group, cued into feedback affordances more frequently than other classmates. He routinely listened for the beep that told him he had given the correct response. He used all the feedback affordances to understand where he was in the level and what he needed to do to advance to the next one. Paek (2012), Paek (et al 2011, 2013) presented that interactions, audio, and visual feedback had significant impacts on first and second graders’ learning. Jay expressed a sense of accomplishment when he saw JiJi moving across the screen or up the vertical bars. This was also true for David and Mike, who were also higher academic performers. The feedback afforded validation for all these students on their correct responses. Other studies have documented the benefits of instant feedback from iPad game-based apps (Attard & Curry, 2012).

On the other hand, Dana, Ann, and Chase, who were lower academic performers, did not cue into affordances for validation but for self-correction. The affordance that helped them the most was, when they counted incorrectly, the objects would drop to the bottom of the screen and turn red, which stopped JiJi from crossing the screen. This let them know that they had given the incorrect response. The software would then let the preschoolers repeat a similar problem. These lower-performing students accessed immediate feedback more often to permit self-correction. The real time feedback instantly contextualized the learning tasks for the students. (Leichtenstern, Andre, & Vogt, 2007) found similar results about learning materials being contextualized by instant feedback.
Overall, the iPad worked better with the older children in the room than the younger children. The more mature and independent the student was, the more beneficial the iPad and apps tended to be. Regardless, all participants increased in number sense, despite initial educational or technological ability, according to pre- and post-assessments. This cannot be solely attributed to interactions with the iPad; the rich, contextual mathematics environment cultivated by the teacher through active and creative lessons must also be acknowledged.

Conclusion

This research strived to contribute to the limited amount of literature about preschoolers’ interactions with mathematics number concept apps. Themes and patterns found on affordances accessed by preschoolers during intervals of play with various early number apps were reported. Furthermore, this study gathered app constraints that designers should consider when constructing number sense apps for digital play for young learners. The results concerning affordances and constraints have vital implications for designers of number sense apps since small devices are being used more and more often in early educational classrooms for the learning of mathematics. The mathematics community must be aware of how preschoolers are interacting with and perceiving affordances, and whether those affordances are facilitating learning.

The research concluded that the touch sensitive device is an appropriate educational technology for the preschool classroom. All children in the study increased in number sense knowledge after interacting with the device for 15-30 minutes a day for 14 weeks. While not all learning of number sense can be attributed to the iPad apps, the apps did provide students with individualized opportunities to practice foundational mathematical skills. Students, parents, and teachers considered the iPad a safe, beneficial educational experience for learning.
Appropriate teaching tool which offers an engaging learning space for preschoolers.

In this study, an engaging learning phenomenon was documented by video recordings and communication with teachers, parents and students: iPads can provide a digital space in which preschoolers can learn. The handheld device is being used by preschool populations in the car, at home, and during the school day. The iPad possesses the ability to construct a digital learning atmosphere to foster learning with many of the familiar and traditional teaching methods emphasized as effective teaching strategies. Dewey stressed the importance of considering the experience of the child when learning. Documentation from videos, student interviews, and teachers depict students having positive learning experiences.

The participants in this study were young (4–5-years-old), so somedays they preferred other activities. However, the criteria for this study was 3 iPad sessions a week for 10 minute intervals for a duration of 14 weeks. This totals 30 minutes a week for fourteen weeks, which equals 420 minutes cumulatively, the minimum criteria for iPad interactions over the study’s duration. However, the ST Math computer generated detailed report indicated that the preschoolers spent between 826-910 minutes interacting with iPads over the fourteen-week study. Most preschoolers enjoyed using the iPad as part of their learning activities in and outside of the school classroom.

Documentation via video recording of students’ gestures and expressions captured events such as children clapping for themselves when they completed tasks correctly or vocalizing their enthusiasm with responses such as “Yeah! I did it!” Consider the following examples:

Interviewer: What do you like about the iPad?

Alex: When JiJi, that JiJi has different levels that are different!

Mike: I like to count and to play.
Ann: It helps me with my numbers.

(Alex, Mike, Ann personal communications; May 22, 2018)

During an interview, Miss Smith, Miss Newman’s aide, acknowledged that ST Math provided students opportunities to learn early math skills in a fun and exciting way (V. Smith, Personal Communication, May 16, 2018). Another teacher commented that most students are familiar with the iPad and most preschoolers like playing games, so when your present math in a game format they did not see it as math, just a game (F. Day, Personal Communication, May 17, 2018).

These snippets of participants’ voices prove their overwhelmingly positive experiences when interacting with the studied number sense iPad apps. Further evidence that participating preschoolers had enjoyable learning experiences and positive associations with iPad play is found in the element of sensory responses, which helped the young children focus. The rich, varied scenarios offered by the mathematics apps involving numbers sense tasks and concepts created an interactive space that allowed for the movement of manipulatives, audio, visual, and touch counts. This variety stimulated the participants to learn numbers in a new way. As always, careful consideration must be given to the implementation of apps by teachers, including the content provided on the app as curriculum, the differentiation the app gives to students, and the ease of use of the apps selected. Ultimately, not all educational apps are created equal.

Attard and Curry (2012)’s qualitative study looked at how teaching and learning practices and student engagement were influenced by the integration of the iPad. The research took place in an elementary school; the class was participating in a Department of Education and Communities iPad trial and were provided with thirty iPads for the classroom for six months. The participants were female and male of mixed abilities in mathematics and from a low to
middle socioeconomic status. In this study, data was collected with semi-structured interviews, focus groups, and observations. From this research, the finding most relevant to the current study is that the teacher reported that portable devices, when used in small group activities, allowed for a more student-centered approach in learning. The teacher expressed views similar to those of the teachers in the current study in that he saw the technology as a way for students to practice and improve mathematics skills. The teachers and researchers perceived student engagement with mathematics was increased by the use of the iPad. Some students reported cognitive engagement through challenging problems framed in a game environment. The research found that the iPad increased opportunities for interactions with mathematical concepts and encouraged a wide range of activities to support learning discovery. The teacher clarified that drill and practice type problems usually displayed in a game format promoted student engagement. Another important finding from this study emphasized the importance of variety in mathematics curriculum, as opposed to stagnancy, another benefit of iPad classroom integration (Attard & Curry, 2012). This finding was reinforced in the current research study.

The game-based, tiered-accomplishment number sense app provided students an enjoyable experience. The app increased engagement by giving the preschoolers different, tiered levels accomplishments. Each had a variety of number sense tasks and game-like scenarios that created personalized learning, if desired, or collaborative learning, if desired. At a very young age, students choose to interact with technology, people, or both in the pursuit of learning. What a beautiful experience of learning in its purest form. The higher performing students did exhibit slightly more interest in getting to the next level and competition within the game-based apps. However, students of at all academic performing status showed excitement about getting JiJi to the next level.
This enthusiastic response to the integration of gaming into mathematics and other STEM classrooms is reflected in Clark and Ernst’s (2009) research. Their study investigated the implementation of varied technological tools in STEM education at the middle and high school levels. Although their focus involved an older population, the overwhelmingly positive response resonated with the current study: more than ninety percent of their participants approved of educational video game incorporation. Pertinent findings relevant to the current research were that “mathematics games increase engagement, motivation, and student learning” (Clark & Ernst, 2009).

Of course, the iPad should not be the only source of mathematical content provided to the child. The observed preschool in this research study did an excellent job of providing students with creative learning avenues in which to learn foundational concepts of mathematics. The teachers created visual, kinesthetic movement, hands-on, manipulatives-based activities, sang songs, and read books about number sense. When implementing iPads, teachers should consider a balanced approach to teaching time and incorporate iPad preschool play evenly among the other educational, play-driven activities.

**Appropriate tool that fosters collaboration.** As traditional teachers go, Vygotsky is most interested in the idea that students, when learning, should be enabled to share their ideas with others and receive input from others about their thoughts. This is a source of confirming, questing, or learning from each other. The iPad’s portability and easily maneuverable dimensions can create a space for meaningful conversations around mathematics concepts.

The following is a strong example captured via video recording that illustrates how young students might collaborate during iPad play. The teachers in this study routinely used iPads in small group settings, which fostered an environment of opportunity for students: the
opportunity to share knowledge with one another about mathematics. On more than one occasion, the researcher observed students helping one another advance through ST Math’s levels. There was always a teacher accessible to the students when working in the small group setting so they could actively share their thoughts or voice questions. Additionally, pictures were taken throughout the duration of the investigation depicting students working in small groups and pairs. They would often inquire, chat, explain, or learn from and with one another. The researcher concluded that iPad play can support collaborative learning experiences.

During one of the iPad sessions in Miss Day’s room, two students played side-by-side. Alex played the ten frame adding game, while Mike played the JiJi parachute game. The JiJi parachute game was designed with a variety of visual displays that some students found challenging. In the parachute scenario, students must place boxes in amounts greater than, less than, or equal to another set of boxes. Two stacks of boxes sit on each side of the screen. Students must stack the boxes on the right side according to what mathematical symbol they are given. For example, if a “less than” symbol is displayed between the two stacks, the boxes on the right must be greater than the stack of boxes on the left. Another example would be that, if the “equal to” symbol is given, both stacks of boxes must be the same height.

Mike was having a hard time understanding what was expected of him within the parachute game. Alex was adding with the ten frame, and was completing the tasks with accuracy.

Mike, when answering a problem incorrectly: No!

Mike, when answering another problem incorrectly: OOOH!

Alex: I have already worked that game.
Mike then worked a few more problems incorrectly and gestured with his hand, indicating his discouragement.

*Alex, leaning over:* Let me show you.

An “equal to” task is displayed onscreen.

*Alex, pointing to the sign:* That is equal to, so both of the stack of boxes have to be the same. It like that when you see the ladder.

It should be noted that a visual symbol of a ladder within the game signifies an “equal to” problem. Mike then fills in the left side of boxes to match the boxes on the right and achieves the correct answer. Next, the scenario of the game changes slightly and students are presented with number symbols this time, with the” less than,” “greater than,” and “equal to” symbols. A number 5 is displayed on the screen and a “less than” symbol.

*Alex, touching the number 6 for Mike:* 5 is less than 6.

Other research has arrived at similar findings, such as Lena Lee (2014) studied 3-5-year-olds in a low economic area in a preschool program in the Midwest of the United States. In this study, participating children learned with digital play. The case study qualitative approach included a pre-assessment and a post-assessment, as well as observation; direct quotes are given in the article help further explain student interactions with iPads to demonstrate meaningful learning for children. The students used the iPad 45 minutes two times a week for a full semester. Lee’s (2014) research concentrated on young children’s learning and explored how children used iPads for the meaningful learning. The findings focused on the social interactions and collaboration opportunities that the iPad provided for young children. The research found that the iPads allowed student to have meaningful conversations with peers. Lee concluded conversations with teachers enhanced students’ learning, motivation, and encouragement. The
research provided evidence that young children have enjoyable learning experiences when playing with iPads (Lee, 2014).

**Appropriate because it offers matched learning levels to preschool children.** To Piaget, the cognitive level of a learner is important so that student ability matches task difficulty. Interviews with both teachers in this study indicated that ST Math can be used for individualized learning. Miss Newman, the main teacher in this study, stated “iPad play can provide differential instruction depending on the needs of the child.” (Newman, personal communication, May 17, 2018). She went on to say “Kids work on ST Math individually” and they can “go at their own pace.” She describes the iPad as a tool for individualized instruction (Newman, personal communication, May 17, 2018). Since the iPad is acting as a teacher for a range of children who perform at varying academic levels, it must be able to provide these students at various abilities with curriculum at various levels of difficulty. Another teacher said, “A certain amount of tries to learn a lesson helps them with the lesson that they are having issues with” (F. Day, Personal Communication, May 17, 2018). This demonstrates the iPad’s flexibility when it comes to curriculum: students who have not yet mastered the content have the ability to practice until they achieve mastery.

**Affordances.** Since all preschoolers are in the process of constructing concepts of numbers, the most accessed affordance was the visualization of a simple touch count when practicing counting. Again and again, this interaction was performed by the preschool students in counting objects. Most apps provide alteration in visual display by adding a color to the objects being counted. Sometimes, objects being counted after a touch would move or make a noise.
This action of touch and response worked like the moving and pointing of physical manipulatives that children so often use when learning to count.

Regarding affordances and constraints, the main study navigating similar research terrain (preschoolers’ curriculum) was Moyer-Packenham, et al.’s (2016) research investigating the role of affordances in children’s learning. This mix-methods study investigated one hundred students ranging from preschool to second grade and incorporated qualitative and quantitative methods. Its qualitative methods emphasized video recordings to document accessed affordances and children’s interactions. Ultimately, the findings most relevant to the current study were threefold: firstly, that the feedback provided by affordances and constraints allowed young learners to self-correct their mistakes; secondly, that preschool learners who utilized a “helping affordance” were more likely to improve in accuracy; and thirdly, that a transition was observed among some participants from counting one blocks to recognizing a group of ten one blocks as a unit, increasing their efficiency and abilities with two-digit numbers (2015).

Furthermore, the current research findings reinforced Moyer-Packenham’s (2015) finding that whether an affordance is accessed by a learner depends on that learner’s ability. The current study found that affordances are accessed by students with varied number sense ability and technology skills in different ways. Some affordances afforded cues for one type of student but did not for another. It must be stated that, from observation alone, researchers cannot discern if an affordance is either unacknowledged or intentionally ignored.

Moyer-Packenham’s (2015) study additionally found that students who accessed affordances became more accurate and efficient when dealing with two-digit numbers if the students used both the ten rod and one units to work with two-digit numbers. In the current study, transcription of video recordings shows Jay working with numbers 11-20. In the Alien
Capture scenario, Jay is counting spaceships. He quickly taps on each spaceship as they are animated into the mother spaceship. The mother spaceship represents the unchanging unit of 10. During Jay’s interaction with the virtual spaceships, as he touches them, they change color and move into the mother spaceship. As he touches the spaceship, he says “I already know it’s going to be ten!” This comment indicates that he understands the unchanging unit of 10 much like the 10 rod used in Montessori mathematics instruction. As he advanced in the game-based app, he encountered the numbers 12, 19, 14, and 13, for which he accurately identified quantities without counting. His touch counts were quick, correct, and showed understanding.

**Concrete manipulatives.** This research proves that preschool learners benefit from a combination of physical and virtual manipulatives when learning fundamental mathematics. This is evident in the case of Dana. Video captured Dana, a lower performing student, working on a simple subtraction problem (3-2) with concrete manipulatives. There are five people counters on the table to work with. The following is a transpiration of a video recorded conversation between the researcher and Dana, as well as a narrative to describe action with the manipulatives.

*Researcher:* What does this problem tell you that you need?

*Dana:* 3.

*Researcher:* Show me three.

Then, Dana moves 2 people counters away from the group of 5.

Dana, as she moves the first counter: 1.

Dana, as she moves the second counter: 2.

Dana, as she moves the third counter: 3.

Now, Dana has 3 people counters in front of her to start the process of solving the problem 3-2.
Researcher: What does the problem tell you to do?
Dana: Take away.
Researcher: Take away how many?
Dana: Ummmm… two.
Researcher: Wow do you take away two?
Then, Dana begins to move the people counters.
Dana, moving the first people counter away: 1.
Dana, moving the second people counter away: 2.
Researcher: How many is left?
Dana, holding the last people counter in her hand: 1.
Researchers: Can you show me on the iPad?
Dana selects one box at the bottom of the screen to indicate one and pushes the enter bottom.

Dana is an example of one of the preschoolers in the study that made use of concrete manipulatives to accurately respond to challenging tasks within the number sense apps. The concrete manipulatives aided her in seeing all the mathematical steps of subtraction in this case. It gave her a concrete visualization of the problem with a tactile movement that the iPad did not offer in this particular instance. She was able to manually move the people counters in correspondence to the subtraction problem 3-2. She also benefited from the researcher’s questioning, which helped guide her through the process of subtraction.

Dana was one of multiple participants who engaged in this amalgamation of concrete and virtual manipulatives. Another participant who benefited from this strategy is David, as evinced in video transpiration of David’s actions when working with a digital moveable number line on
the iPad. David works on ordering numbers 1-100 on the digital number line. The app gives David a number, for example 87, and he has to first find the interval 80-90 on the digital number line and then select the marker which would represent 87 on the number line. Since the iPad number sense app prompts a number at random, David has some trouble locating the desired destination of the number. So, the teacher gives David a 100 number chart, which displays the numbers 1-100, in order to guide him. Next, the number 42 appears on screen. Then, David looks at the 100 chart to see that 42 is in between 41 and 43. He quickly finds the interval 40-50 and is able to locate the marker where the 42 should be. He uses the 100 number chart for the first level of the game and is then able to complete the second and third levels of the game without using the 100 chart. The use of the chart, a concrete manipulative, aided David because he could see the ordering of the numbers 1-100. The chart provided a visual display of the numbers both forward and backward; by reviewing the numbers briefly in this manner, David was able to complete the task on the iPad more accurately after using it for a short time. This is another example of how concrete manipulatives help a student work through tasks on number sense apps.

The current research findings support similar findings by Aronin and Floyd (2013), whose research suggest that the utilization of both physical and digital manipulatives should be encouraged when implementing iPad apps for learning. The current study found that preschool learners clearly benefited from the use of both materials and digital play. This is reinforced by Aronin and Floyd’s (2013) research, which suggests that iPad educational apps are enhanced by concrete manipulatives to promote understanding in young learners as they make connections about intangible mathematics concepts through tangible materials.

In conclusion, the iPad and various mathematics-based apps are another beneficial educational activity to add to the already-existing array of teaching strategies implemented in the
preschool classroom. Preschoolers learn in different ways depending on their learning styles, their number sense knowledge, their technology skills, and their problem-solving abilities. Educational apps offer yet another alternative for young children to learn. The iPad can be used to bridge the understanding of mathematics for most preschool students. Its array of advantages in the preschool setting include: a game-based structure proven to enhance student engagement, the incorporation of multimodal learning affordances, individualized learning, opportunities for collaboration, and differentiated instruction. The iPad’s functionality allows young learners to practice fundamental concepts necessary for future mathematics success, and has been proven to be particularly effective when used in conjunction with concrete manipulatives for some young learners. All students in this study showed an increase in number ability during the 70-day investigation; ultimately, this research found the iPad bridged understanding for preschool learners.

Limitations

The study took place at only one school setting. The researcher only had access to two rooms within the school. There were a small number of participants. There was only one researcher that entered the classroom to work and observe the children. The children all came from a similar low economical background. Even though the research was collected for 14 weeks, a longer duration might have shown more number sense growth. Additionally, more interactions with the iPad might have been observed. The researcher had to abide by the teachers’ teaching instructions and schedule in the classroom with respect to the ST Math software. Other apps were restricted in use and not observed as much as the ST Math app. After nine weeks or so, students in Miss Newman’s class became a little bored with the ST Math app because she used it for thirty minutes a day. However, students in Miss Day room did not get as
bored with the app because it was not incorporated as heavily into her lessons. Since ST Math was used so frequently in the classroom, it was difficult to fit other app experiences in the curriculum. The students’ attitudes and moods were sometimes a limitation because they did not always feel like playing. The researcher had to be flexible with the children and encourage them. Their age and capability for concentration had to be considered. In the student interviews, the students’ articulations about the iPad were limited due to the fact they were only 4 to 5 years in age.

Recommendations

When implementing number sense iPad apps into the preschool classroom, the researcher would suggest devoting a whole center to technology. Such a center would benefit young children to by acquainting them with a digital learning environment which they will encounter in their future educational experiences. Fostering number sense concepts with a sound variety of apps permitting children to have choice in their digital mathematical play will work best in meeting the learning needs of preschoolers. Previous research has also recommended incorporating different mathematics apps on the iPad for best results (Car, 2012).

The main investigator of this study concludes that apps should display simple game and puzzle scenarios that instruct basic foundational mathematics skills such as counting, identifying, ordering, comparing, one-to-one correspondences, representation of quantity, making pairs of ten, and simple addition and subtraction problems. The scenarios and tasks should not be repetitive but have brief intervals due to the short attention span of young children. The apps must have differentiation so that the children’s academic level can be matched to the tasks. The virtual manipulatives should be larger images to assist the child in counting and touching. The researcher observed that if the objects on the screen respond in some way to the touch count, it
gives the child more accuracy in performance. The apps used in this research would change colors, make movements, or produce sound. Some objects would respond in more than one way. A variation of free-moving manipulatives to access and interact with would be recommended. Children should have freedom in how long they play the iPad and number sense apps.

Prior research has indicated that engagement, motivation, and student learning can be improved with the use of mathematical games (Clark & Ernst, 2009). Additionally, other research results reveal that children in early elementary years are instinctively absorbed with play-based content (Spencer, 2013). The main investigator in this study believes that, since there is not a well-developed criterion for how game-based apps impact the learning of mathematics concepts in young learners, there is a need for further research that would investigate, observe, and evaluate how children’s playing impacts learning on the iPad.

Forthcoming studies are needed to fully understand how and when to use the iPad with mathematical concepts in the preschool classroom. Studies that look at preschooler’s interactions with number sense apps can give further insight on how the device should be implemented into the classroom as an interventional educational tool. Future studies should delve into what type of student would benefit the most from the number concept apps. The researcher would suggest a larger participant sample size in which more low-, average-, and higher-achieving students could be observed. Additionally, longer duration of investigation could bring about greater details providing a more holistic picture of affordances that help students learn on the touchscreen device. More research is needed on affordances and constraints of number sense apps so that designers can more effectively create apps for preschool learning.

Previous research discusses the need for upcoming studies to explicitly address best practices for technology integration and student learning in the classroom (Ronau et al., 2014;
Tzuo, Toh, & Liang, 2015; Lee, 2015; Spencer, 2013; Carr, 2012). The researcher in this study agrees that this would be necessary for excellent teaching strategies to be employed. The investigation of technology integration has the potential to directly impact teachers’ decisions about implementation. Former research proposes that inquiries should continue to examine appropriate pedagogical approaches that can be established for early children’s learning and their play with technologies. Professional development opportunities that educate teachers about effective implementation of technology in the classroom should be established (Lee, 2015). The main investigator in this study concurs that professional development for teachers would facilitate best practices.

Determining appropriate pedagogical approaches for technology can support educators through the technological integration process to maximize student knowledge. Further research is needed to adequately evaluate the impact and effect of iPads on the learning process (Spencer, 2013). Moreover, future research is needed for a complete understanding of the impact of iPads on preschool mathematics achievement. This research is important for bridging the gap in research literature and providing valuable information for teaching in the 21st century. Further research needs to narrow down what affordances and constraints are needed to provide effective educational experiences for preschools to gain number sense knowledge through iPad interactions.
Appendix A

The TEMA questions 1-22 are aligned appropriately for young children ages 3 to 5 and is the portion of the instrument that will be used. When considering the first 22 questions, this section shows the relationship of the questions to the categories of informal and formal mathematics. Informal mathematics questions relating to numbering are 1, 2, 3, 5, 6, 10, 11, 12, 13, 21, and 22. Informal mathematics questions relating to number comparisons are 4, 19, and 20. Informal mathematics questions relating to calculation include 8 and 16. Informal mathematics questions relating to concepts are 7 and 9. Also there is a list of formal mathematics questions. Formal mathematics questions are related to numeral literacy questions 14 and 15. Formal mathematics in relation to concepts seen in question 18. Questions 1-22 were not in relationship to formal mathematics number facts and formal number calculation (Ginsburg & Baroody, 1990).

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<thead>
<tr>
<th>Question</th>
<th>Item Name</th>
<th>Stimulus</th>
<th>TEMA Questions Assessment:</th>
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<tbody>
<tr>
<td>1.</td>
<td>Perception of Small Numbers</td>
<td>How many cats do you see?</td>
<td>Concepts of small number</td>
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<td>2.</td>
<td>Produce Finger Displays</td>
<td>Show me ___ fingers.</td>
<td>Concept representation of numbers -TEMA asks the students to produce fingers</td>
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<td>3.</td>
<td>Verbal Counting by Ones 1 to 5</td>
<td>Count them for me.</td>
<td>Concepts of counting by ones 1 to 5 on both</td>
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<td>4.</td>
<td>Perception up to 10 items</td>
<td>Which side has more?</td>
<td>TEMA uses sets of dots.</td>
</tr>
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<td>5.</td>
<td>Nonverbal Production 1 to 4 items</td>
<td>Make yours just like mine.</td>
<td>TEMA is matching object to object (representation to representation).</td>
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<td>6.</td>
<td>Enumeration 1 to 5 items</td>
<td>You count the stars.</td>
<td>Concept of counting</td>
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<td>7.</td>
<td>Cardinality Rule</td>
<td>How many stars did you count?</td>
<td>Concept of cardinality</td>
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<td>Description</td>
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<td>8.</td>
<td>Nonverbal (Concrete) + &amp; -</td>
<td>Make yours just like mine.</td>
<td>Addition and subtraction</td>
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<td>9.</td>
<td>Number Constancy</td>
<td>How many tokens are there?</td>
<td>Addresses quantity as a constant regardless of arrangement</td>
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<td>10.</td>
<td>Produce Sets Up to 5 items</td>
<td>Give me ____ tokens.</td>
<td>TEMA uses concrete manipulatives and the stimulus was not a verbal request.</td>
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<td>11.</td>
<td>Produce Finger Displays to 5 Verbal Counting by ones: one-to-one0</td>
<td>Hold up _____ Fingers.</td>
<td>Concept of Counting by ones up to 10 and student produces finger displays</td>
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<td>12.</td>
<td>Verbal Counting by ones up to 10</td>
<td>1, 2, 3, now count by yourself.</td>
<td>Concept of Counting by ones up to 10</td>
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<td>13.</td>
<td>Numbers after 1 to 9</td>
<td>What number comes next ____ and then comes ____?</td>
<td>TEMA asks “number after.”</td>
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<td>14.</td>
<td>Reading Numerals: Single-Digit Numbers</td>
<td>What number is this?</td>
<td>TEMA uses verbal response from student to numerical symbols.</td>
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<td>15.</td>
<td>Writing Numerals: Single-Digit Numbers</td>
<td>Write this number.</td>
<td>TEMA has student write numerals on paper.</td>
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<td>16.</td>
<td>Concretely Modeling Addition Word Problems Sums up to 9</td>
<td>How many does he have altogether?</td>
<td>TEMA has student adding tokens.</td>
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<td>17.</td>
<td>Part- Whole Concept</td>
<td>How many ____? ____ +3 = 5 ____ + 4 = 7</td>
<td>Complicated concept on TEMA assessment</td>
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<td>18.</td>
<td>Written Representation of Sets up to 5</td>
<td>Show me how many there are.</td>
<td>TEMA has student write number symbol to match representation.</td>
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<td>19.</td>
<td>Choosing the Larger Number: Number Comparisons 1 to 5</td>
<td>Which is more ……..?</td>
<td>TEMA is completely verbal. Students are questioned about choosing the larger number and visual representation are used.</td>
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<td></td>
<td>Choosing the Larger Number: Number Comparison 5 to 10</td>
<td>Which is more…….?</td>
<td>In TEMA this question is answered with a completely verbal response. No visual representation is given in correspondence to the 5 or 10 when you have to ask students to choose the larger number.</td>
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<td>20.</td>
<td>Verbal Counting by Ones: to 21</td>
<td>Count up as high as you can.</td>
<td>Verbal counting to 21</td>
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<td>22.</td>
<td>Number After 2- Digit Numbers to 40</td>
<td>What number comes next ___ and then Comes _____?</td>
<td>Two digit numbers</td>
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Appendix B

Observation protocol for observation of Head Start students’ interactions with number sense iPad apps.

Observation Protocol

Time of observation:
Date:
Place:
Identification of the Child being observed:

Observational Field notes for the iPad session:

What did the student play today on the iPad?

Notes regarding improvement of interaction with iPad apps:

Notes about affordances accessed by student today:

What affordances, features, or indicators does the child show a physical reaction to?

Student’s perceived mood toward the iPad apps:

Level of student’s perceived engagement with the iPad apps:

Reflective notes:

Navigation check-list:

___ Can the child turn on the iPad?
___ Can the child navigate between apps?
___ Can the child turn up the volume?
___ Can the child follow indicators?
___ Can the child follow voice directions/questions/commands?
___ Can the child complete their 10-min session?
    If not, note time of off-task behavior: ______
___ Can the child fix internet access problems?
Performance task measured: number of times student correctly identifies numbers 1-10 over Weeks 1-6.

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Performance task measured: number of times student correctly orders number sequences 1-10 over Weeks 1-6.

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Performance task measured: number of times student correctly matches quantities 1-10 to numeral representations 1-10 over Weeks 1-6.

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Performance task measured: number of student’s correct and incorrect answers over Weeks 1-6.

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<th>Correct answers</th>
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Performance task measured: number of times student accesses signifiers to successfully complete tasks.

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Performance task measured: number of times student utilizes scaffolding to successfully complete tasks.

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Appendix C

Coding Book

CV1 - Virtual manipulative changes color after touch count
CV2 - Virtual manipulative shakes after touch count
CV3 - Virtual manipulative makes a sound after touch count
CV4 - Virtual manipulative is connected to a number symbol after touch count
CV5 - Virtual manipulative shakes and makes a sound after touch count
CV6 - Preschooler counts out loud in addition to touch count where virtual manipulative changes color, shakes, makes a sound, connects to a number symbol

TASK1 - Completed task correct in counting
TASK1N - Completed task incorrectly in counting
TASK2 - Completed task correct in cardinality
TASK2N - Completed task incorrectly in cardinality
TASK3 - Completed task correct in ordering
TASK3N - Completed task incorrectly in ordering
TASK4 - Completed task correct in identifying
TASK4N - Completed task incorrectly in identifying
TASK5 - Completed task correct in addition
TASK5N - Completed task incorrectly in addition
TASK6 - Completed task correct in subtraction
TASK6N - Completed task incorrectly in subtraction
TASK7 - Completed task correct in comparing numbers
TASK7N - Completed task incorrectly in comparing numbers
TASK8 - Completed task correct in operation and algebraic thinking
TASK8N - Completed task incorrectly in operation and algebraic thinking
TASK9 - Completed task correct in number and operation in base ten
TASK9N - Completed task incorrectly in number and operation in base ten
TASK10 – Completed task correct in geometry
TASK10N – Completed task incorrectly in geometry
TASK11 – Completed task correct in measurement and data
TASK11N – Completed task incorrectly in measurement and data

SCE1 – Followed the How many legs scenario correctly
SCE1N - Did not follow the How many legs scenario correctly
SCE2 – Followed the Parachute scenario correctly
SCE2N – Did not follow the Parachute scenario correctly
SCE3 – Followed the How many Sides/Corners scenario correctly
SCE3N – Did not follow the How many Sides/Corners scenario correctly
SCE4 – Followed the Counting to 20 scenarios correctly
SCE4N – Did not follow the Counting to 20 scenarios correctly
SCE5 – Followed the Position – Match Direction scenario correctly
SCE5N - Did not follow the Position – Match Direction scenario correctly
SCE6 – Followed the Treasure Hunt with boxes scenario correctly
SCE6N – Did not follow the Treasure Hunt with boxes scenario correctly
SCE7 – Followed the Paper JiJi scenario correctly
SCE7N – Did not follow the Paper JiJi scenario correctly
SCE8 – Followed the Sorting & Classifying scenario correctly
SCE8N – Did not follow the Sorting & Classifying scenario correctly
SCE9 – Followed the Composing Shapes scenario correctly
SCE9N – Did not follow the Composing Shapes scenario correctly
SCE10 – Followed the Bar Graph scenario correctly
SCE10N – Did not follow the Bar Graph scenario correctly
SCE11 – Followed the Dot Shape scenario correctly
SCE11N – Did not follow the Dot Shape scenario correctly
SCE12 – Followed the *Foundation of Place Value* scenario correctly
SCE12N – Did not follow the *Foundation of Place Value* scenario correctly
SCE13 – Followed the Introduction to the *Number Line* scenario correctly
SCE13N – Did not follow the Introduction to the *Number Line* scenario correctly
SEC14 – Followed the *Making 10* scenario correctly
SEC14N – Did not follow the *Making 10* scenario correctly
SEC15 – Followed the *Bouncing Shoes to 10* scenarios correctly
SEC15N – Did not follow the *Bouncing Shoes to 10* scenarios correctly
SEC16 – Followed the *Bird Lift* scenario correctly
SEC16N – Did not follow the *Bird Lift* scenario correctly
SEC17 – Followed the *Alien Captured* scenario correctly
SEC17N – Did not follow the *Alien Captured* scenario correctly
SEC18 – Followed the *Ten Frame Counting* scenario correctly
SEC18N – Did not follow the *Ten Frame Counting* scenario correctly

GRO – Preschooler counts number 11-20 with a touch count using 1’s blocks
GRO 1 – Preschooler counts number 11-20 with touch count of group 1’s into a ten unit

PPATH – Preschooler is motivated to get to the next level by progression path
PPATH1 – Preschooler is not motivated to get to the next level by progress path

CM1 – Preschooler uses cards in addition to affordance in app to complete task
CM2 – Preschooler uses counts in addition to affordance in app to complete task
CM3 – Preschooler uses charts in addition to affordance in app to complete task
CM4 – Preschooler uses number line in addition to affordance in app to complete task
CM5 – Preschooler does not use anything but affordance in app to complete task
COL1- Preschooler works one to one with iPad to complete task
COL2- Preschooler works with peer on the iPad to complete task
COL3 – Preschooler works with teacher on the iPad to complete task
COL4 – Preschooler works with teacher aid on the iPad to complete task
COL5 – Preschooler works with researcher on the iPad to complete task
COL6 – Preschooler works in small groups on the iPad to complete task

STM 1- Basic Counting – Connects visual representation of quantity to written symbol
(Affords opportunities for child to link written symbol to representation)

STM 2- Basic Counting – Different object changes color as child touches each object
(Affords opportunities to practice counting)

STMDC3-Dot Count – Connects number of objects to written symbol using one-to-one correspondence. After child touch the object, the written symbol pops up on the screen (Affords connection to visual representation of quantity to written symbol via one to one touch correspondence)

STMDC4-Dot Count – Connects visual representation of number to quantity on number path at the bottom of the screen (Affords repetitive counting of object to the number path which is a building block to understanding a number line)

STMDC5- level 3 -Practice counting with touch counts 1-20,
(Affords child practice counting)

STMHML1- Practice of basic counting for number 1-10
(Affords child practice counting)

STMHML2- repetitive counting in which the shoes change color and the written number is connected to visual representation

STMHML-3 shoes change color as child touches shoes and written symbol pop up
(Affords connection between quantity and written symbol, legs to shoes)

STMHML4 Animated shoes attached to legs
(Affords child correct or incorrect response, shows how many more are needed or how many less)

STMS1-Sticks are providing for the child to identify the number and then connect that number to correct representation (affords connection to written symbol to quantity representation)
STMS2-Objects are given; children must connect number of object to written symbol
(affords connection of quantity representation to written symbol)

STMA11-works on numbers 11-20
STMA22-Alien ships change colors as children touch and count them
STMA33-Alien ships are group into a set of 10 units
STMA44-Alien ships are displayed into a ten frame for quantity of number

STMFA1-Awards of a beep given for correct feedback
(Affords a sound cue for the right answer)
STMFA2-Award of visual animation of JiJi crossing the screen from left to right to move to next level
(Affords a visualization for the right answer)
STMFA3-JiJi Body at the bottom of the screen gives visual cues to child of how many problems they can miss and still progress to next level (Affords a visualization of how many questions the student can miss)
STMFA4-The percentage bar at the bottom of the screen by JiJi Bodys affords visualization for the student’s progress within app level (Affords progress obtained by student)
STMFA5- As student complete levels, JiJi climbs visual vertical bars to represent the completion of a level within a modular (Affords visual cue of completion)
STMFA6-When child counts incorrectly the objects drops to the bottom of the screen and turns red which stops JiJi from crossing the screen (Affords visual cue of incorrect answer)
STMFA7-If incorrect answer is given student repeats similar problems
(Affords child repeated practice of incorrect response)

TMBC2-Basic Counting – Object move as child touches each object (Affords opportunities to practice counting)
TMBC3-Basic Counting – Feedback produces an audio response when user touches each object (Affords indication of 1-to-1 correspondence)
TMBC4-Basic Counting – Eliminates possibility of incorrect answer—(Affords a model for solution)
TMSD1-Same or Different – Cards flip as child selects them—(Affords opportunities to practice matching)
TMNT1-Number Tracing – Links visual representation of quantity while child traces the written symbol (Affords opportunities to connect representations)
TMNT2-Number Tracing – Child traces the written symbol with signifiers that give direction—(Affords opportunities to learn written symbols)

TMNT3-Number Tracing – Kids voice pronounces written symbol after it is traced by the child (Affords opportunities for child to connect written symbols to verbal pronunciation)

TMNT4- Number Tracing - Award celebration stars are given for correct feedback (Afford a cue to the correct response)

TMNT5-Number Tracing – As children touch each block when counting there is a clicking noise (Affords cues of 1-to-1 correspondence)

MN120-1 to 20-Connects written symbol to representation with verbal pronunciation of example number (Affords child to connect symbol, representation, and verbal pronunciation)

MNQ1-Quantity-Can you count five? Connecting representation of blocks to written symbol (Affords opportunities to connect representation to written symbol)

MNQ2-Quantity-As child moves block into answer box, verbal pronunciation of “one”, “two”, “three”, are given (Affords indication of 1-to-1 correspondences)

MNQ3-Quantity-Award celebration stars are given for correct answers (Affords a cue to accurate answer)

MN1-100 Board-Orders Numbers (1-10) as student moves written symbol, verbal name is pronounced (Affords connection of written symbol and verbal pronunciation)

MN2-100 Board-Orders Numbers (1-100) (Affords opportunities to practice ordering numbers 1-100)

MNN1-Numeral- Connect Verbal name to written symbol when asked “Can you find (1, 2, 3, …n)” (Affords opportunities to connect verbal name to written symbol)

MNN2-Number-Feedback is given by dropping the number of blocks correlated to the example number (Affords cue to the correct response)

MNN3-Number-Feedback is given by dropping the number of blocks correlated to the example number (Affords opportunities to connect verbal name to written symbol and representation)

MNN4-Number-Focused on numbers programmed by teachers. (examples: (1 to 9), (10 to 99), (100 to 999) (Affords opportunities for individualized learning levels)

MNNQ2-Numerals (from quantity) – Connecting representation to written symbol and verbal name (Afford opportunities to connect representation, written symbols, and verbal name)
MNNQ3-Numerals (from quantity) – Focuses on numbers 1-20 (Affords opportunities for children to learn number 1-20)

MNT3-Tracing-While children are tracing the touch marks are highlighted with moving 2-D pictures such as stars or bubbles to give children immediate feedback with tracing direction. (Affords opportunities for children to learn how to write numbers)

MNT5-Tracing-Focuses on numbers 0-9 (Affords opportunities for children to learn numbers 0-9)

MS1-Pink Tower-Moving of solid cubes (Affords opportunities to learn small, medium, large dimensions and relations)

MS2-Ordering numbers 1, 2, and 3 (Affords opportunities for ordering symbols)

MS3-Matching representation of written symbol to representation (Affords opportunities to match written symbol and representation)

MS4-Ordering representation of beads (Affords opportunities to learn order quantities of numbers)

MS5-Ordering representation of beads (Affords opportunities to learn smallest to largest representation)

MS6-Connects visual representation of quantity to written symbol (Affords opportunities to connect representations)

MS7-Object changes color as child touches each object (Affords opportunities to practice counting)

MS8-Interactive virtual manipulatives are free moving (Affords individualized learning)

MS9-Interactive reward games (Affords student opportunities to engage mathematics in a positive way)

MS10-interaction with Montessori Manipulatives in a viral environment (Affords for students to learn number concepts)

EL1-Videos-Child connects counting exercise to videos (Affords a comfortable/Familiar learning environment)

EL2-Coloring activity- connect written symbol to representation (Affords tangible interaction in digital color options)

EL3-Sort by quantity (Afford opportunities to follow verbal directions connected to movable representations of practiced number)

EL4-Seek and Find (Affords discover of symbols from a landscape)

EL5-Interactive Puzzle (Affords connection to symbols and representation)

EL6-Summy chart (Affords teacher/results ability to monitor students’ progress)
EL7-Numerals (from quantity) – Focuses on numbers 1-20 (Affords opportunities for children to learn numbers 1-20)
Appendix D

Questionnaires for Parents

Q1 My Child's ethnic background is:
   White (1)
   Black or African American (2)
   Hispanic (3)
   Asian (4)
   American Indian (5)

Q2 Please rate your technology knowledge using a scale from 0 to 10
   A rate of 0 would suggest your strongly disagree with the statement.
   A rate of 5 would suggest you neither agree/disagree with the statement.
   A rate of 10 would suggest you strongly agree with the statement.
   _____ I can troubleshoot my own technical issues. (1)
   _____ I quickly learn new technologies with ease. (2)
   _____ I stay up-to-date on new technologies. (3)
   _____ I often play with technology. (4)
   _____ I am familiar with a variety of different technologies. (5)

Q3 Please rate your child’s technology knowledge using a scale from 0 to 10
   A rate of 0 would suggest your strongly disagree with the statement.
   A rate of 5 would suggest you neither agree/disagree with the statement.
   A rate of 10 would suggest you strongly agree with the statement.
   _____ I can troubleshoot my own technical issues. (1)
   _____ I quickly learn new technologies with ease. (2)
   _____ I stay up-to-date on new technologies. (3)
   _____ I often play with technology. (4)
   _____ I am familiar with a variety of different technologies. (5)

Q4 Does your child play with technology such as a home computer, video game system, or cell phone?
   Yes (1)
   No (2)

Q5 Does your child play on an iPad outside of school?
   Yes (1)
   No (2)
   If yes, please estimate average time spent per day:

Q6 My child's access to technology in school is currently regular and adequate.
   Extremely adequate (1)
   Somewhat adequate (2)
   Neither adequate nor inadequate (3)
   Somewhat inadequate (4)
   Extremely inadequate (5)

Q7 My child has strong technology skills.
   No Opinion (1)
   Strongly Disagree (2)
   Disagree (3)
   Agree (4)
Q8 My child is encouraged to use technology at school.
No Opinion (1)
Strongly Disagree (2)
Disagree (3)
Agree (4)
Strongly Agree (5)

Q9 My child frequently uses technology at home to learn pre-school concepts.
No Opinion (1)
Strongly Disagree (2)
Disagree (3)
Agree (4)
Strongly Agree (5)

Q10 I assist my child in using technology for learning.
No Opinion (1)
Strongly Disagree (2)
Disagree (3)
Agree (4)
Strongly Agree (5)

Q11 Among all the needs facing schools today, where would you rank technology?
0 (0)
1 (1)
2 (2)
3 (3)
4 (4)
5 (5)
6 (6)
7 (7)
8 (8)
9 (9)
10 (10)

Q12 Where does your child most frequently use the iPad? Select all that apply.
   ______ In the automobile (1)
   ______ Home (2)
   ______ While waiting (3)
   ______ While traveling (not in the car) (4)
   ______ Friend or relative's house (5)
   ______ In a restaurant (6)
   ______ While shopping (7)
   ______ At school (8)

Q13 What activities does your child do on the iPad? Select all that apply.
   ______ Take pictures/selfies (1)
   ______ Listen to music (2)
   ______ Watch educational cartoons or videos (3)
   ______ Watch entertainment cartoons or videos (4)
______ Play entertainment games (5)
______ Play educational games (6)
______ Communicate with family or friends via Skype, FaceTime, phone calls, etc. (7)

Q14 Why does your child stop playing with the iPad?
You make them stop (1)
They choose something else (2)
They get bored (3)
The battery runs out (4)
Another reason (5)

Q15 Does your child play with mathematics apps that teach numbers?
Yes (1)
No (2)

Some of these questions were modified from:


Appendix E

Student Activity Worksheet

Student Activity Worksheet

Name: ___________________
Class/Date: _______________

1. Number Identification (Score 1 point for each correct item): ______________________________
   __________________________
   ______________________________________________________
   __________________________

2. Counting: 3 _____, 5 ______, 14 ______, 30 ______

3. Quantity Discrimination: _____________________________________
   ______________________________________
   ________________________________________
   ___________________________________________________________________

4. Quantity to Numbers: 7_____, 12_____, 5 _____, 50 ______

5. Missing Number
   ____________________________________________________________
Number Identification

1. Instructions “Tell me the name of each number 1 point to.”
2. Score = 1 point for each correct item. (Time = 1 min)

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Counting

Instructions “Count the circles.”
Score = 1 point for each correct item. Four items total.
Time = 3 min – max 45 seconds per problem
Child can self correct.

Example: A
Example B
Example C
Quantity Discrimination

1. Time = 1 min. Start timer after student’s first answer.
2. Instructions “Tell me the name of the larger number in each pair.”
3. If child spends more than 3 seconds, “Let’s go to the next number.”
4. Score = Total Correct

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Quantity to Number

1. Instructions: “Count the circles, then point to the correct number. If you do not know, say I don’t know.”
2. Score = 1 point correct item.
3. Time – 3 minutes
Missing Number 1 to 20

1. Time – 1 min. Start timer after student’s first answer.
2. Instructions “Tell me the name of the missing number.”
3. If child gets stuck for 3 seconds, “Let’s go to the next one.”
4. Score = Total Correct

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Appendix F

Semi-Structured Interview Questions for Students

1. Do you like playing with the iPad? What do you like about it? or What do you not like about it?
2. Do you have an iPad at home? If yes, what do you do with it at home?
3. What is your favorite mathematics app that you played with during your iPad sessions here at school? Why?
4. Did you find it helpful that the app provided direction with icons?
5. Did you like it when the app would let you know if you got something right or wrong on a mathematics problem?
6. How did you like moving the virtual manipulatives (objects) on screen?
7. Do you feel like mathematics is easier on the iPad? If yes, how is it easier? If not, why?
8. What most helps you learn numbers from the iPad apps?
9. What was the most challenging part of using the iPad?
10. What was the easiest app? What made it so easy?
11. What was the hardest app? Why was it so hard?
12. Were you ever confused? What about?

Some of these questions were modified from:


Potential follow-up questions to supplement the above semi-structured interview questions may include the following:

- Why was it your favorite mathematics app? What did you like about it?
- What did you like about playing with the mathematics apps?
- What was your favorite feature of the app?
- Did you like the music that was on the app?
- Did you find it helpful when the app voice would give directions?
- Did you enjoy the counting activities on the apps?
- Tell me about your experience with the iPad. Tell me what you did with the iPad.
Appendix G

Semi-Structured Teacher Interview Questions

How do you use the iPad in your classroom?
What is your daily routine with the iPad?
What have you found is beneficial about the iPad? What do you think the students learn?
How do you think the iPad helps students learn?
Can you describe [participant name]’s personality?
Can you describe [participant name]’s academic performance?
Does [participant name] enjoy playing on the iPad?
Appendix H

Secondary Apps Reviewed but not Utilized in this Study

**TouchCounts.** TouchCounts provides a digital platform for students to explore number concepts such as naming, counting, ordering, cardinality, and arithmetic. The app can support foundational concepts such as less-than, greater-than, equal-to, and skip counting. Children are able to use touch, vision, and hearing to learn and develop stronger number sense. TouchCounts provides a mathematics exploration environment in which students can learn. It allows them to create and study their own questions.

**Count, Sort and Match.** The app focuses on preschool mathematics concepts such as counting, sorting, and matching. This app provides counting, tracing, and sorting activities by both size and color. This provides an engaging element such as virtual manipulatives to move, colorful graphics, and clear directions. The app was featured in “Kids Best iPad Apps” in May of 2013 and was developed by Ripple Digital Publishing.

**Basic Skills.** This app provides a variety of activities in which the child moves virtual manipulatives to complete the tasks. For example, the app may ask the child to match pairs with animal figures or toys. The app has several exercises that allow children to count objects, such as balloons and toys. The app provides prompts for the child, such as touch the smallest or largest toy. The app incorporates creative components by allowing children to design the carts on a moving train between learning tasks. The app has won the Parent’s Choice Award and was developed by Studios 22 Learn, an award-winning education developer.
## Appendix I

**ToDo Mathematics**

<table>
<thead>
<tr>
<th>Domain</th>
<th>Rubric Rating</th>
<th>Rating Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Demand (adapted from Mathematics App 2015)</td>
<td>Procedures with connections (4)</td>
<td>Task in the app require user to demonstrate and investigation of complex relationships and relate concepts.</td>
</tr>
<tr>
<td>Mathematics Content</td>
<td>The content in the app is handled appropriately and builds on prior knowledge (4)</td>
<td>Counting and Cardinality, Data Measurement, Geometry, Time and Money, Number Operations</td>
</tr>
<tr>
<td>Engagement (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>The student is highly motivated to use the app (4)</td>
<td>The app is highly motivating and engaging for young children.</td>
</tr>
<tr>
<td>Feedback and Scaffolding (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>Student is provided with general feedback. Exporting the student feedback is difficult or limited (3)</td>
<td>Feedback is given to redirect students toward the correct answers.</td>
</tr>
<tr>
<td>Differentiation (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>The app can easily be altered to meet the needs of diverse learners (3)</td>
<td>The app can provide limited differentiation in that the app progresses in difficulty, this addresses differentiation in that harder or easier activity can be selected for a student.</td>
</tr>
<tr>
<td>Ease of Use (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>Student is able to launch and independently use the app (4)</td>
<td>The tasks and activities are easy to follow.</td>
</tr>
</tbody>
</table>
### Appendix J

**Montessori Numbers**

<table>
<thead>
<tr>
<th>Domain</th>
<th>Rubric Rating</th>
<th>Rating Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Demand</td>
<td>Procedures with connections (4)</td>
<td>Task in the app require user to demonstrate and investigation of complex relationships and relate concepts.</td>
</tr>
<tr>
<td>Mathematics Content</td>
<td>The content in the app is handled appropriately and builds on prior knowledge (4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counting Ordering Tracing Numbers Matching Quantity to Representation</td>
<td></td>
</tr>
<tr>
<td>Engagement</td>
<td>The student is highly motivated to use the app (4)</td>
<td>The app is highly motivating and engaging for young children. It provides a digital version of the Montessori’s activities.</td>
</tr>
<tr>
<td>Feedback and Scaffolding</td>
<td>Student is provided with general feedback. Exporting the student feedback is difficult or limited (3)</td>
<td>Feedback is given to redirect students toward the correct answers.</td>
</tr>
<tr>
<td>Differentiation</td>
<td>The app can easily be altered to meet the needs of diverse learners (3)</td>
<td>The app can provide limited differentiation in that the app progresses in difficulty, this addresses differentiation in that harder or easier activity can be selected for a student.</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>Student is able to launch and independently use the app (4)</td>
<td>The tasks and activities are easy to follow.</td>
</tr>
</tbody>
</table>
Appendix K

Pink-Tower App

<table>
<thead>
<tr>
<th>Domain</th>
<th>Rubric Rating</th>
<th>Rating Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Demand (adapted from Mathematics App 2015)</td>
<td>Procedures with connections (3)</td>
<td>Tasks in app implicitly or explicitly call for particular procedures or algorithms, but do so to make connections to underlying concepts</td>
</tr>
</tbody>
</table>
| Mathematics Content             | The content in the app is handled appropriately and builds on prior knowledge (4) | • Discrimination of dimensions  
• Understanding of difference in size  
• Learning dimensions of large, medium, and small |
| Engagement (Tony Vincent; retrieved from: static.squarespace.com) | The student is highly motivated to use the app (4) | The app is highly motivating and engaging for young children. It provides a digital version of the Montessori’s Pink Tower activities. |
| Feedback and Scaffolding (Tony Vincent; retrieved from: static.squarespace.com) | Student is provided with general feedback. Exporting the student feedback is difficult or limited (3) | Feedback is given to redirect students toward the correct answers. Students can retry on the building of the tower. |
| Differentiation (Tony Vincent; retrieved from: static.squarespace.com) | The app can easily be altered to meet the needs of diverse learners (3)     | The app can provide limited differentiation in that the app progresses in difficulty, this addresses differentiation in that harder or easier activity can be selected for a student. |
| Ease of Use (Tony Vincent; retrieved from: static.squarespace.com) | Student is able to launch and independently use the app (4)                  | The tasks and activities are easy to follow.                                                                                                    |
# Appendix L

## Mathematics Shelf

<table>
<thead>
<tr>
<th>Domain</th>
<th>Rubric Rating</th>
<th>Rating Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Demand</td>
<td>Procedures with connections (3)</td>
<td>Tasks in app implicitly or explicitly call for particular procedures or algorithms, but do so to make connections to underlying concepts</td>
</tr>
<tr>
<td>(adapted from Mathematics App 2015)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematics Content</td>
<td>The content in the app is handled appropriately and builds on prior knowledge (4)</td>
<td>Subitize, identify numbers 1-10, match numbers to quantities, order quantities, magnitude, decomposing numbers, place value, add and subtract within 10, multiplicative reasoning</td>
</tr>
<tr>
<td>Engagement</td>
<td>The student is highly motivated to use the app (4)</td>
<td>The app is highly motivating and engaging for young children. It provides many different interactive activities for the learning of number concepts</td>
</tr>
<tr>
<td>(Tony Vincent; retrieved from: static.squarespace.com)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback and Scaffolding</td>
<td>Student is provided with general feedback. Exporting the student feedback is difficult or limited (3)</td>
<td>Feedback is given to redirect students toward the correct answers. Voice features provide positive feedback when children select the correct answers</td>
</tr>
<tr>
<td>(Tony Vincent; retrieved from: static.squarespace.com)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Differentiation</td>
<td>The app can easily be altered to meet the needs of diverse learners (4)</td>
<td>The app is differentiated by giving students a placement test and then tailoring the app to the children’s needs</td>
</tr>
<tr>
<td>(Tony Vincent; retrieved from: static.squarespace.com)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease of Use</td>
<td>Student is able to launch and independently use the app (4)</td>
<td>Students can load the app easily. The app icon is easily recognizable on the home screen. The tasks and activities are easy to follow</td>
</tr>
<tr>
<td>(Tony Vincent; retrieved from: static.squarespace.com)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Appendix M

#### TouchCounts

<table>
<thead>
<tr>
<th>Domain</th>
<th>Rubric Rating</th>
<th>Rating Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Demand (adapted from Mathematics App 2015)</td>
<td>Procedures with connections, doing mathematics (4)</td>
<td>This app serves as a virtual tool for students. Depending on how it is used, it could fit into any of the categories in the rubric. It has potential to be a level 3 or 4</td>
</tr>
<tr>
<td>Mathematics Content</td>
<td>The content is handled appropriately and builds on prior knowledge (4)</td>
<td>Identify numbers, match number to quantities, order numbers &amp; quantities, counting by 2, counting by 3, counting by 5</td>
</tr>
<tr>
<td>Engagement (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>The student is highly motivated to use the app (3)</td>
<td>Provides students digital opportunities to practice counting</td>
</tr>
<tr>
<td>Feedback and Scaffolding (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>Student is provided with general feedback. Exploring the student feedback is difficult or limited (1)</td>
<td>No feedback</td>
</tr>
<tr>
<td>Differentiation (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>The app can easily be altered to meet the needs of diverse learners (1)</td>
<td>No differentiation but could be added by teachers</td>
</tr>
<tr>
<td>Ease of Use (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>Student is able to launch and independently use the app (4)</td>
<td>The app is easy to use</td>
</tr>
</tbody>
</table>
## Appendix N

**ELMO Loves 123**

<table>
<thead>
<tr>
<th>Domain</th>
<th>Rubric Rating</th>
<th>Rating Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Demand (adapted from Mathematics App 2015)</td>
<td>Memorization procedures with connections (3)</td>
<td>Memorization-recognize Arabic numbers 1 to 20. Procedures without connection, counting to a certain number</td>
</tr>
<tr>
<td>Mathematics Content</td>
<td>The content in the app is handled appropriately and builds on prior knowledge (4)</td>
<td>Counting numbers 1 to 20; recognize and write Arabic numbers 1 to 20; addition and subtraction by counting</td>
</tr>
<tr>
<td>Engagement (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>The student is highly motivated to use the app (4)</td>
<td>Users are allowed to choose a game style: watching video (to learn how to count), color the number (write Arabic numbers), or mathematics games (count and recognize Arabic numbers). Users are allowed to select the number to practice with. The app provides fun videos and music</td>
</tr>
<tr>
<td>Feedback and Scaffolding (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>Student is provided with general feedback. Exploring the student feedback is difficult or limited (4)</td>
<td>Feedback is provided for each action (the sound of “ding,” subjects change posture). Feedback is given to redirect students toward the correct response (“aha, this is not the correct answer”)</td>
</tr>
<tr>
<td>Differentiation (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>The app can easily be altered to meet the needs of diverse learners (3)</td>
<td>The app asks the user to choose a number to play with, enabling user to customize game level.</td>
</tr>
<tr>
<td>Ease of Use (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>Student is able to launch and independently use the app (4)</td>
<td>App is easy to use</td>
</tr>
</tbody>
</table>
## Appendix O

### Count, Sort and Match

<table>
<thead>
<tr>
<th>Domain</th>
<th>Rubric Rating</th>
<th>Rating Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Demand (adapted from Mathematics App 2015)</td>
<td>Procedures with connections (3)</td>
<td>Ask children to complete the toy pattern, find the correct shape, count the objects, sort the clothes into small, medium, and large</td>
</tr>
<tr>
<td>Mathematics Content</td>
<td>The content in the app is handled appropriately and builds on prior knowledge (4)</td>
<td>The app focuses on counting, sorting, matching</td>
</tr>
<tr>
<td>Engagement (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>The student is highly motivated to use the app (4)</td>
<td>The app provides several different learning tasks and interactive activities. The app has colorful graphics to keep young children engaged.</td>
</tr>
<tr>
<td>Feedback and Scaffolding (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>Student is provided with general feedback. Exploring the student feedback is difficult or limited (4)</td>
<td>Gives verbal cute to children if they are right or wrong. If they get the answer right, they get bursting stars</td>
</tr>
<tr>
<td>Differentiation (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>The app can easily be altered to meet the needs of diverse learners (1)</td>
<td>No differentiation was used just activities surrounding counting, matching, and sorting</td>
</tr>
<tr>
<td>Ease of Use (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>Student is able to launch and independently use the app (4)</td>
<td>App is easy to use, an easy interface</td>
</tr>
</tbody>
</table>
# Appendix P

## Basic Skills

<table>
<thead>
<tr>
<th>Domain</th>
<th>Rubric Rating</th>
<th>Rating Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Demand (adapted from Mathematics App 2015)</td>
<td>Procedures with connections (3)</td>
<td>Ask children to complete the toy pattern, find the correct shape, count the objects, match the toys, make a train, make pairs, and touch the toy of the same size.</td>
</tr>
<tr>
<td>Mathematics Content</td>
<td>The content in the app is handled appropriately and builds on prior knowledge (4)</td>
<td>The app focuses on counting, patterns, sorting, and matching.</td>
</tr>
<tr>
<td>Engagement (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>The student is highly motivated to use the app (4)</td>
<td>The app provides several different learning tasks and interactive activities. The app has a cute bear for the narrator of activities which provides positive feedback to participants. The app blends content and creative tasks nicely.</td>
</tr>
<tr>
<td>Feedback and Scaffolding (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>Student is provided with general feedback. Exploring the student feedback is difficult or limited (4)</td>
<td>Gives verbal cues to children if they are right or wrong. If they get the answer right, they get bursting stars.</td>
</tr>
<tr>
<td>Differentiation (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>The app can easily be altered to meet the needs of diverse learners (1)</td>
<td>No differentiation was used just activities surrounding counting, matching, and sorting.</td>
</tr>
<tr>
<td>Ease of Use (Tony Vincent; retrieved from: static.squarespace.com)</td>
<td>Student is able to launch and independently use the app (4)</td>
<td>App is easy to use, an easy interface</td>
</tr>
</tbody>
</table>
Appendix Q

Worksheet for the collection of field notes and artifacts
Time of observation:
Date:
Place:
Identification of the Child being observed:

Observed Classroom Activity:

Artifacts Collected (will be attached with final report):

Observed Behavior:

Perceived level of engagement with the Mathematics lesson:

Childs perceived level of Comprehension, or Successful completion of activities:

Child interaction with other classmates, staff, and teacher:

Another relevant Notes:
Appendix R

Coding of the interview

Day Interview
1  Duration 10:23
2  Adkins: So how do you use the IPads in your classroom, like, what’s your routine?
3  Day: We use our IPads daily. We use them once a day during our DI groups which is our
differentiated instruction. Where we do is four different small groups. One group of
children is on IPads while, two groups are with the teacher, and one group is doing an
independent activity.
4  Adkins: And how long normally are those sessions?
5  Day: Um, they’re 15, about 15 minutes, and they vary probably from 10-20 minutes but
6  average 15.
7  Adkins: And I remember you were telling me yesterday that not every student gets the IPad
everyday?
8  Day: Yeah. So it would end up being, they, each group, we have four groups, red, orange,
yellow, and green, so green group would get the tablet twice a week because it would be
every other day. Because one time they are in, on carpet in their independent activity and
one time they’re on tablets so they don’t get two because there is not enough IPads,
there is five.
9  Adkins: How do you feel about using ST math? You know, do you think it improves their
Math scores? Like how do you feel?
10 Day: I do think it helps them because they’re, it’s something that they do, um, practically
daily or every other day. Um, and it’s just practice, it’s trial and error and so they get to
experience it on their own and it’s like a safe environment for them because they don’t
have everybody watching them. And they don’t have everybody, you know.
11 Adkins: Independent practice,
12 Day: Yeah. So it’s basically try it until you get it right and, um, because basically that’s what
it is, is they have a certain amount of tries to learn a lesson to help them with the lesson that
they have issues with and kids are on IPads and TVs for the majority of their at home
time. So it’s something they are familiar with and like to do. Most kids like doing games
so when you present it to them as that they don’t see it as math, they see it as a game,
they see it as oh ok, I want to win. And it gets them in that mentality.
13 Adkins: I do see that. I do see that a lot of times they want to get to the next level and they
want to get it correct.
14 Day: Yes.
15 Adkins: So that’s been interesting. So I worked with three of your kids and I guess I’m just
looking for descriptors of their personality and their math ability. So I worked with   Alex,
Jay and Mike…
16 Day: Jay has always been one of my higher level kids not necessarily because he came in
with those skills it’s just that he learns very quickly and he likes to be right and he likes
to, he likes to be the first one to answer.
Adkins: Yeah, I feel like out of all the kids that I work with he is one of the most mature kids and what I’ve noticed is you can set him independently alone and he can work through the IPad sessions where other kids might need provoking but he just is incredibly independent.

Day: Yes.

Adkins: And I just wanted, I guess you see that.

Day: I do. He is very independent and he is very, he is more mature than the other ones and he can handle independent activities more than most, um, and he loves to learn.

Adkins: Well that’s good.

Day: So he likes to be right. And you know that’s a great motivator for him.

Adkins: So as far as like in the classes, he’s among one of your highest students or?

Day: He is one of the highest students overall not only in Math but also in literacy and writing and self-help skills and social skills. He’s my all around high one in my higher group.

Information 54-73 about participant not in the study

Adkins: …

Day: …

Adkins: …

Day: …

Adkins: …

Day: …

Adkins: …

Day: …

Adkins: …

Day: …

Adkins: …

Day: …

Adkins: And then Malcolm is the last one.

Day: Um, yes, Malcolm, he started as one of my red students as I would say. He was one of my lowest ones. He is now in my second high group overall in literacy and in math. And in Math I can definitely see is, he has excelled with the app. He is the highest student right now on ST math.

Adkins: On ST math?

Day: On ST math he is the highest.

Adkins: That’s crazy.

Day: And he loves it. He is very engaged in it and he wants to know if he has a problem he will come to you and he will ask.
Adkins: Um, yeah, I think that’s true. He will say, he’ll tell me when he needs help. And I see him wanting to get the answers correct. And how do you describe his personality as far as in terms of a group?

Day: Um, he is one of the ones that I can count on to do the right thing.

Adkins: OK.

Day: He has a lot of integrity. He wants to do the right thing. He wants to know that his friends are doing the right thing, being on task. You know being, doing what they’re supposed to be doing. And he, he helps, he spots me in that aspect. He’ll tell them all the teachers are waiting for you to be quiet. You know what it’s time for us to do this we’re not doing this anymore. He’s very good at regulating himself and others.

Adkins: That’s good.

Day: Yeah. And you know he’s usually because of his speech um, he has sometimes a lot of difficulty communicating across with others but he’s one, he’ll will try at least three times to get his point across. After the third time he may choose to, you know, drop it and just move on or he may choose to push it further. Most likely it’s something that he is very adamant about.
Newman Interview

1. Duration 13:45
2. Adkins: Okay, so it’s Monday morning here at [name of] academy and I’m interviewing the
   main teacher…
4. Adkins: Project so, I would just like you to describe how you use the iPads in your
   classroom.
5. Newman: Okay, um, I use it mainly just as a math tool in my classroom that’s what my main
   focus is with the technology, uh, primarily using ST math. Um, as I have the kids work on
   ST
   math individually and as I see them get stuck on a certain standard or stuck on a certain
   game
   or a skill then that’s when I’ll then focus my lesson plan on and then teach them that skill and
   progress it so that way it’s individualized.
7. Adkins: And then they, what I’ve observed, is you have two centers morning and evening
   and the kids rotate. One of the rotations in the centers is the iPad and so they hit that once or
   twice a day?
9. Adkins: And you try to work with them approximately how many minutes with them in
   those centers?
11. Adkins: About 20 minutes. And what do you see the benefits of using the technology? Like
   what, what is the thing that you like the best about using ST math in your classroom?
12. Newman: Well it’s, Like how I mentioned, it’s individualized and so it goes at their pace,
   how, if they are progressing really fast and they’re understanding the skill then they can
   . move on ahead rather when you’re just teaching a lesson when you’re trying to hit the
   whole
   group on a lesson you miss the high kids and you miss the low kids or you miss the kids in
   the
   middle. When you use the IPads, when you’re using a game, it, they can go at their own
   pace, then I can track what they’re doing and then like I said I can then plan my lesson
   plan...
15. Newman: ……. information from line 29-80 about participant not include in study
16. Adkins: ……
17. Newman: ……
18. ……
19. ……
20. ……
21. ……
22. ……
23. ……
24. ……
Adkins: ……
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subtract and understand that part so that was really nice. And how would you describe his personality?

Newman: Um, he’s one that’s very affectionate and a people pleaser but at the same time needs a lot of praise. Um, he often needs to, needs reinforcement as he’s working out his activity. So otherwise he loses confidence.

Adkins: I also worked with Chase. So how would you describe his personality?

Newman: Um, he’s kind of a downer. He looks at things like glass half empty. Um, and so it’s sometimes hard to get him motivated to do things. However, um, if you pair him up with his friends or someone that he likes to play with he will get into the activity. Um, but if you stick him by himself then kind of shuts down. So you gotta stick him with other kids who are more positive and who like want to do it and they help motivate him to do it.

Adkins: And how would you describe his math skills?

Newman: Um, fairly average. He’s pretty much right where he’s supposed to be for preschooler. Um, he was very low at the beginning of the year and now he’s, like I said, he’s average for preschool. He’s hitting the standards that is expected for this grade.

Adkins: And how did, what did you observe about with his interaction with the IPad? I observe sometimes he did fine if he want to do it, he did fine, he could follow along.

Newman: Yeah, yeah. He was just fine with it, he enjoyed it but..

Adkins: Right. Like he never refused it.

Adkins: ……information from line 105-124 about participant not include in study

Newman: ………

Adkins: ………

Newman: ………

Adkins: ………

Newman: ………

Adkins: ………

Newman: ………

Adkins: Dana?

Newman: Dana, she’s another social one. Um, she really doesn’t do well by herself, um, with anything.

Adkins: Yeah, almost, like I saw this relationship between her and José you know almost like a codependency.
Newman: Yeah, she’s very codependent on other people. There’s certain kids in the class that she is constantly around but not in a good way. Like when she, like all she wants to do is socialize so she has a hard time focusing on academics because all she wants to do is socialize with her friends.

Adkins: And how do you see her math skills are or how have they changed? I do think that she has gotten better with the numbers 11-20.

Newman: She has gotten better but she still on the lower end. I still have concerns in the math area with her, um, but like I said that’s because she’s, she doesn’t really care for the IPad but she doesn’t really care for academics in general.

Adkins: Right and I did find too with her from the IPad it was the level. So if the level is too hard for her…

Newman: She’s not going to.

Adkins: She’s not going to interact with it or give it a chance.

Newman: Yes,

Adkins: information from line 144 – 150 about participant not include in study

Newman: …

Adkins: …

Newman: …

Adkins: …

Newman: …

Adkins: …

Newman: And Ann is the same way

Adkins: Really?

Newman: She’s very, she was very low um, would lose confidence very easily and like to the point where she’ll start crying.

Adkins: Yeah, she doesn’t want to play it if…and she will tell you, you have to help me.

Newman: Yeah, she doesn’t want to do it by herself, Even if she can do it she thinks she can’t.

Adkins: Right and I noticed that you use a lot of hands on visuals, modeling with her. I think that that helped as well. And then just to wrap up the very last question, just tell me a little about yourself. How long you’ve been teaching? How long have you been here?

Newman: Um, I’m new at teaching this is my second year in the classroom. I’ve been with this school with three years though. I started off in special ed as an interventionist. And then this is my second year as a lead teacher. Um, I’m from a special ed. back ground and working with kids individually so that’s why I try to find as many ways as I can to make things individualized for the student and so that’s why I gravitate towards the IPad in using that technology for math at least. Because I felt like a weakness I knew of myself of how to teach math. Um, and so that’s where I’m at that’s how I use, I found it to use as a tool to individualize it probably because of my background in special ed.

Adkins: Alright, thank you so much.
Appendix S

Example of Narrative Log

**Number and Objects to 10: Number Sticks** – The numeral 8 appears on the screen. Then the symbol is animated and turns into 8 sticks in the form of the numeral 8. Several events can occur at this point. The child can know the number and not need to count the sticks to identify the quantity of the number 8. The child can count the sticks and touch 8 tally marks at the bottom of the screen. The child cannot use or recognize the need to count the sticks. The child can ignore the sticks all together. When the child touches the tally marks at the bottom of the screen, they turn green. When the correct number of tallies are colored in, the child hits the enter button. If the child touches the incorrect number of tallies, the tallies fall to the bottom of the screen in red to indicate incorrectness. This process is done for numbers 1-10. The main affordance is that the child counts the sticks to identify the number. Then connects that tallies to represent quaintly by touch counts. This affords the child an opportunity to connect quantity of the number to symbol of the number. The Sticks are provided for the child to identify the number and then connect that number to correct representation. A ding after the correct response in the game affords a cue to the correct response. In addition, JiJi crossing the screen affords a visual cue to the correct response.

**Number and Objects to 10: Practice Counting**—When objects such as apples, bananas, pigs, and shoes are displayed on the screen, students must touch each object. As they touch the object, it turns a color. Sometimes the objects on the screen would shake or move, other time the object on the screen may make a noise. Sometimes more than one visualization of touch would happen. Often as the child would touch the objects on the screen they would count out loud. The child then must identify the symbol that corresponds to the objects at the top of the screen. Doing this activity some students will count out loud as they touch each object on the screen. Some students will miss count by skipping an object on the screen. Most students need and must use a touch count to correctly count the virtual manipulative provided on the screen. This counting practice affords the child an opportunity to connect quantity of the number to the numeral symbol. A ding affords a cue to the correct response. A repeated action in all the games is JiJi crossing the screen to afford a visual cue to the correct response.

**Numbers to 10: Dot Count**—Different objects and numbers of objects are displayed on the screen. The child then touches each object and counts. When the child has finished, he or she colors in the corresponding number boxes at the bottom of the screen. If the child is correct, the boxes are then animated and the symbols for each box appear. The boxes are then pulled together and dropped into a line of boxes representing a number line. This repetition affords the child counting practice and one to one correspondence. It also reinforces symbol to quantity. If the child incorrectly counts the objects they are displayed in red. This affords child counting practice and one to one correspondence. The ding affords a cue to the correct response. JiJi crossing the screen affords a visual cue to the correct response.

**Ordering Numbers**—The task is to order number 1,2,3, and so on, but the child cannot identify the numbers. The child touches each number and lets the audio voice on the app pronounce the number. The pronunciation of the number affords them an opportunity to correctly order the numbers. Some children do not touch multiple numbers because they already know the ordering of numbers. The pronunciation of the written symbol allows the child to hear the name of the number thus allows correctness in ordering. The pronunciation affords child to connect verbal number to written symbol.

**How Many Legs?**—Displayed on the screen was a certain number of red shoes. The child then counts the red shoes and select the correct characters with same number of legs to correspond to the red shoes. There are illustrated characters with different numbers of legs at the top of the screen. For example, the lamp has one leg. The ostrich has two legs. The robot has three legs. The dog has four legs. The star has five legs. The ant has six legs. The insect has seven legs. The octopus has eight legs. The bus has nine legs. The lobster has ten legs. The child counts the legs on the characters to select the correct number of legs for
the shoes. This exercise is a building block for a more advanced level of addition and subtraction. In which the same characters and legs are displayed. In the addition and subtraction task for example, 8 red shoes are displayed on the screen. Then the child will select pairs of characters with correct number of legs that would be added together to represent 8. In this case the child could select the insect with seven legs and the lap with one leg. They might select two doges with four legs or the ant with 6 legs and the ostrich with two legs. Only the student with higher preforming number sense was able to complete the task of adding and subtracting with the characters. If the child incorrectly selects characters that do not add or subtract to the correct number of displayed red shoes, then the red shoes animate and go on the legs, but some legs will not have a shoe. This animation allows the student to see visually that the incorrect characters where selected. If the correct characters are selected, then each leg has a red shoe. The animation shows a red shoe on each leg and JiJi crosses the screen left to right with a corresponding beep. None of the lower number sense students made it to this level in the game. The average student started the game levels, but did not complete the scenario. The most pronounced affordance was the visual representation provided by the red shoes and legs for adding and subtracting.

Swap Sort—The screen showed a small, large, and medium block in that order. The tomato ate the small one but could not eat the large one. The tomato made a sound, “wonk wonk,” because he could not eat the block without changing the order of the blocks. By using the arrows from above and pressing the button, the iPad allowed the large and medium blocks to change positions so the tomato could eat the blocks and get larger. This afforded the child an opportunity to learn small, medium, and large. This is an introduction to greater than and less than. The tomato size gives cues/immediate feedback to correct response.

Graphing Objects on a Bar Graph—This activity sets in motion the foundation for how to read a graph. The bar graphs are displayed both vertically and horizontally. The student touches and counts different shapes. Then, the child slides a tab on the number line to the correct number of shapes given. As the shapes are animated, the shapes move into the bar graph and light up with color. This affords the child the ability to understand bar graphs. Only the most advanced student made it to this level.

Tracing —A number is displayed on the screen. Children then trace the number with their figure as they touch it. Tracing connects written symbol to verbal name. The app also in the tracing task connects written symbol to quality representation. The child traces the written symbol and uses directing signifiers. While children trace the touch marks, they are highlighted with moving 2-D pictures such as stars or bubbles to give children immediate feedback with tracing direction. This task was a favorite for low performing students due to its non-challenge academic task. Tracing affords opportunities to learn written symbols. In addition, it connects written symbol to verbal pronunciation. It also connects written symbol to quantity.

Number and Objects to 20—There is a certain amount of virtual manipulatives placed on the screen. The task is for the students to count the numbers. Students can count the objects one by one or they can understand how to group 10 ones and use the unchanging unit of ten. This allows student to practice counting, by grouping objects into 10 and then 4 more or 10 and 3 more to get 14 and 13. Lower performing student count the numbers in units on 1’s. For example, if there were 15 objects the lower performing student will count each object. The higher performing students will immediately understand they can group 10 one in to the unchanging unit of ten and only have to count the remaining 5 objects to arrive at 15. This transitioning allows higher preforming students to quickly count numbers 11-20. However, lower performing students do not transition in the grouping of 10 ones and the task of counting was slow and tedious. Visual representations of objects afford students the opportunities to practice counting numbers to 20. Visual representations of grouping numbers into ten and one units affords understanding of base ten.
### Appendix T

<table>
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<th>Students</th>
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<td>Videos</td>
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<td>4</td>
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<td>Student 4</td>
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<td>Videos</td>
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<table>
<thead>
<tr>
<th>Affordance Description</th>
<th>Link visual representation of quantity with written symbols</th>
<th>Interactive manipulatives number rods to explore smallest to largest concepts</th>
<th>Celebration songs or rewards as feedback (affords a cue for the child of a correct answer)</th>
<th>Interactive with beads to represent numbers 1 to 10</th>
<th>Creative puzzle activities</th>
<th>Tracing activities with written symbols</th>
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### Appendix U

**Parent Questionnaires from All Participating Preschoolers**

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<tr>
<th>Question 1: My child’s ethnic background is:</th>
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<tr>
<td>Black</td>
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<tr>
<td>Hispanic</td>
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<tr>
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<td>Hispanic/Asian</td>
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<td>Did not respond</td>
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<tr>
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Please rate your technology knowledge using a scale from 0 to 10

**Question 2. A**

<table>
<thead>
<tr>
<th>Option for answer</th>
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<tr>
<td>I know how to solve my own technical problems</td>
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**Question 2. B**

<table>
<thead>
<tr>
<th>Option for answer</th>
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<td>I can learn technology easily.</td>
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**Question 2. C**

<table>
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<th>Option for answer</th>
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<td>I keep up with important new technologies</td>
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<tr>
<td>Question 2. D</td>
<td>Option for answer</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>I frequently play around with technology</td>
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<tr>
<td>1</td>
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<table>
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<th>Question 2. E</th>
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<td>I know about a lot of different technologies</td>
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<tr>
<td>1</td>
<td>0</td>
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Please rate your technology knowledge using a scale from 0 to 10

Please rate your child’s technology knowledge using a scale from 0 to 10
Please rate your child’s technology knowledge using a scale from 0 to 10.

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<tr>
<th>Question 3. B</th>
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Please rate your child’s technology knowledge using a scale from 0 to 10.

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Please rate your child’s technology knowledge using a scale from 0 to 10.

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Please rate your child’s technology knowledge using a scale from 0 to 10

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<th>Question 4.</th>
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<tr>
<td>Does your child play with technology such as a home computer, video game system, or cell phone?</td>
<td>Yes</td>
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<td>No</td>
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<td>Question 5.</td>
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<tr>
<td>Does your child play on an iPad outside of school?</td>
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<td>The parents reported an average of 2 hours daily play.</td>
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<th>Question 6.</th>
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<tr>
<td>My child’s access to technology in school is currently</td>
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<td>Somewhat adequate</td>
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<td></td>
<td>Neither adequate nor inadequate</td>
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<tr>
<td></td>
<td>Somewhat inadequate</td>
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<td>Extremely inadequate</td>
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<td>My child has strong technology skills</td>
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<td>Strong Disagree</td>
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<td>My child is encouraged to use technology skills.</td>
<td>No Opinion</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Strong Disagree</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Disagree</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Agree</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Strongly Agree</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question 9.</th>
<th>Option for answer</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>My child frequently uses technology at home to learn pre-school concepts.</td>
<td>No Opinion</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Strong Disagree</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Disagree</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Agree</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Strongly Agree</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question 10.</th>
<th>Option for answer</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>I assist my child in using technology for learning.</td>
<td>No Opinion</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Strong Disagree</td>
<td>0</td>
</tr>
</tbody>
</table>
(0 not important all, 5 somewhat important, 10 the most important)

<table>
<thead>
<tr>
<th>Question 11</th>
<th>Option for answer</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Among all the needs facing schools today, where would you rank technology?</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question 12.</th>
<th>Option for answer</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where does your child most frequently use the iPad?</td>
<td>In the car</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>At home</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>While waiting in general</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>While traveling (not in the car)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Friends or relative’s house</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>In a restaurant</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>While shopping</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>At school</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question 13.</th>
<th>Option for answer</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>What activities does your child do on the iPad?</td>
<td>Take pictures/selfies</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Listen to music</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Watch educational cartoons or videos</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Watch entertainment cartoons or videos</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Play entertainment game</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Play educational game</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Communicate with family or friends via Skype, FaceTime, Phone calls</td>
<td>4</td>
</tr>
<tr>
<td>Why does your child stop playing with the iPad?</td>
<td>You make them stop</td>
<td>7</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-------------------</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>They choose something else</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>They get bored</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>The battery runs out</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Another reason</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question 15.</th>
<th>Option for answer</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does your child like to play with math apps that teach numbers?</td>
<td>Yes</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>1</td>
</tr>
</tbody>
</table>

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References


Information Age Publishing.


Teacher beliefs and technology integration practices: A critical relationship.


without disabilities. *Early Child Development and Care, 180*(8), 1005-1017.


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Curriculum Vitae

Amy Beth Adkins
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adkinsa5@univ.nevada.edu

EDUCATION

Ph.D. in Mathematics Education
University of Nevada Las Vegas, Las Vegas Nevada (December, 2018) GPA 3.95
Research Assistantship Summer (2012-2018)

Master of Arts in Education-Secondary
Morehead State University (2007)
Concentration in Mathematics-18 graduate hours completed. GPA 3.923

Bachelor of Arts
Morehead State University (1999)
Double Major in Mathematics and Theatre
Graduated Cum Laude GPA 3.525

Associate of Arts
University of Kentucky-Ashland Community College (1996)
Graduated with High Distinction GPA 3.629

CERTIFICATION
Certificate of Teaching in Secondary Grade 9-12; Rank 2; Commonwealth of Kentucky

PROFESSIONAL EXPERIENCE
Taught the following courses with amount of sections indicated in parentheses:

University of Nevada Las Vegas, Las Vegas, Nevada
Instructor
MATH 96 Intermediate Algebra (3) (Fall 2017-Spring 2018)
EDEL 433/CIE 533 Teaching Elementary School Mathematics (5) (Spring 2013- Spring 2015)

Graduate Research Assistant
The Transitions in Mathematics Middle School (TIMMS) Grant, Dr. Olson, 2016-Current
Rebel Academy, Dr. Beck, 2015-2016
NeCoTip Grant (Nevada Collaborative Teaching Improve Program), Dr. Olson. 2015-2016
MPS Grant (Mathematics and Science Partnership Program), Dr. Shih, 2015-2016
Head Start iPad Implementation, Dr. Shih 2012-2014

Shawnee State University, Portsmouth, OH
Full-Time Senior Instructor of Mathematics
(Fall 2008-Summer 2010) & (Fall 2011-Summer 2012)
   MATH 2410 Mathematics for Elementary/Middle School Teachers I (2)
   MATH 2420 Mathematics for Elementary/Middle School Teachers II (2)
   MATH 1300 Pre-Calculus (1)
   MATH 1500 Principles of Statistics (4)
   MATH 1100 Mathematics Core Course/Problem Solving (15)
   MATH 1020 Intermediate Algebra/Application (11)
   MATH 1010 Basic Algebra with Geometry and Application (3)
   MATH 0099 Begin Algebra (1)

Kentucky Community and Technical College System
Ashland Community and Technical College, Ashland, KY
Full-Time Instructor of Mathematics (Fall 2010-Summer 2011)
   MATH 206 Mathematics for Elementary/ Middle School Teachers II (1)
   MATH 110 Applied Mathematics (2)
   MATH 065 Basic Algebra with Measurement (4)
   MATH 055 Pre-Algebra (4)

Big Sandy Community & Technical College, Prestonsburg, KY
Instructor (Fall 2007-Spring 2008)
   MATH 150 College Algebra and Functions (4)
   MATH 065 Basic Algebra with Measurement (1)

Morehead State University, Morehead & West Liberty, KY
Instructor (Spring 2005-Spring 2007)
   MATH 152 College Algebra (1)
   MATH 093 Intermediate Algebra (2)
   MATH 091 Pre - Algebra (2)

Montgomery County High School, Mt. Sterling, KY
Full-Time High School Mathematics Teacher (2000-2004)
   Taught AP Calculus – 3.5 years
   Created a successful AP Calculus Program at MCHS
   Pre-Algebra, Algebra I, Geometry

Rowan County High School, Morehead, KY
Student Teaching (1999)
   Taught Algebra II, Pre-Calculus, Geometry

PROFESSIONAL SERVICE
Reviewer for National Council of Teacher Mathematics Research Conference April 11-13, 2016, San Francisco
Research Council on Mathematics Learning Proceedings Manuscript Reviewer Orlando Florida
Feb 25-27, 2016
One 5 hr. Professional Development Session for the Mathematics and Science Partnership Program Grant with Dr. Shih
One 5 hr. Professional Development Session for the Nevada Collaborative Teaching Improve Program Grant with Dr. Olson

**Shawnee State University**
- Developmental Math Committee
- Developmental Mathematics Redesign Committee
- Textbook Selection Committee for Mathematics Core Course.

**Ashland Community and Technical College**
- Professional Development Committee Member
- Developmental Math Committee
- Mentee/Mentor Program
- Supplemental Instruction Faculty

**Montgomery County High School**
- Coordinated ACT preparation sessions for MCHS (2003-2004)
- Head coach for MCHS Speech and Drama Team (2002-2004)
- Head coach of McNabb Middle School Speech and Drama Team (2001-2002)

**AWARDS AND SCHOLARSHIPS**

**Teacher Recognition**
**Ashland Community and Technical College**, Ashland, KY
Awarded Certificate of Recognition for Teaching Excellence 2010-2011- Math & Natural Science Division
Graduated from Leadership Tri-State Kentucky, Ohio, West Virginia

**Montgomery County High School**
Recognized by Montgomery Board of Education for consistent academic achievement of students in Advanced Placement Calculus

**Student Recognition**
**University of Nevada, Las Vegas**
Summer Doctoral Research Fellowship (2017)

**Morehead State University**
Alumni Award (1997-1999)
Member of Tutorial Staff for General Mathematics Lab at Morehead State University (1997-1999)
Theatre Scholarship (1997-1998)
Morehead State University Program of Theatre Covington Key Award (1998-1999)
Morehead State University Player’s Award for Best Actress (1997)

University of Kentucky-Ashland Community College
Kentucky Community Transfer Award (1997-1999)
Recognized by University of Kentucky for Notable Accomplishment in the “KEYS to KERA” Project for Service & Learning (1996)
Outstanding Student in Theatre, Ashland Community College (1996)

PUBLICATIONS


PROCEEDING PUBLICATIONS


PRESENTATIONS


Adkins, A., Lockett, D., & DeVaul, L., Number Sense Fun with Game-Based Early Childhood Apps. (April, 2017). San Antonio, TX.


Adkins, A., Technology and Statistics Data. (October, 2016) Presentations at the Regional Conference of the National Council of Teachers of Mathematics, Phoenix, AZ.


Olson, T., & Adkins, A., Case-study Reflections of In-service Teachers on Coursework in the Use of Technology in Mathematics Classrooms (February, 2016). Presentation at the Association


Adkins, A., Shih, J., & DeVaul, L., Lessons Learned about Preschool Children’s Use of iPads. (February, 2015). Presentation at the Association of Mathematics Teacher Educators Nineteenth Annual Conference, Orlando FL.


Shih, J., Adkins, A., & Allen, C., Examining the Effectiveness of iPad Apps in Early Childhood.

Olson, T., DeVaul, L., & Adkins, A., iPad Integration to the Middle School Classroom (Feb 2014). Presentation at the Association of Mathematics Teacher Educators Eighteenth Annual Conference, Irvine, CA.

POSTER PRESENTATION


Adkins, A., iPad Implementation with Head Start Students. (February, 2017) Presentation at the Association of Mathematics Teacher Educators Twenty-First Annual Conference, Orlando, FL.

PROFESSIONAL AFFILIATIONS

School Science and Mathematics Association
Association of Mathematics Teacher Educators
National Council of Teachers of Mathematics
Research Council on Mathematics Learning
Delta Kappa Gamma Society International

PROFICIENCIES

Facilitated: graphing calculators, Excel, Fathom, Geometry Sketchpad, Stats Portal, MathXL, PowerPoint, Blackboard, Elmo, mathematical manipulatives, collaborative learning activities, and applications to enhance learning in the math classroom

REFERENCES

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Las Vegas, NV 89154-3005
(702)895-5340 (office)
Email: jshih@unlv.nevada.edu

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Las Vegas, NV 89154-3005
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