ABSTRACT

Title of Dissertation:	PROMOTING CHILDREN'S EARLY MATHEMATICAL AND STATISTICAL UNDERSTANDING THROUGH PARENT-CHILD MATH GAMES
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Basic statistical literacy is essential for understanding and making inferences from information received from external sources and for developing critical thinking skills necessary for engagement in real-world contexts. However, many children and adults struggle with understanding and interpreting data and graphs. Therefore, it is critical to develop engaging, effective methods for teaching early graphing and data analysis, as they have the potential to enhance children's development of statistical understanding, math, and higher-order thinking skills that remain essential throughout their lifespan. Math games are a common method for teaching math in a way that is engaging and effective for young children. However, few studies have examined games for math content beyond numerical skills. The current study examined the effectiveness of a home-based, experimental graphing game intervention for children's statistical understanding and math skills.

One-hundred-forty-eight 5- to 6-year-old children and their parent were randomly assigned to one of three conditions: graphing board game, graphing card game, or literacy board game, and completed a pretest, 4-week intervention, and posttest. At each test session, children completed statistical understanding and math ability measures. During the intervention, parents and children played games together in their home. Game materials were mailed to families, and families video recorded a session of gameplay at the midpoint of the intervention. Parent and child use of numerical, mathematical, and statistical talk during play were examined.

Children in the graphing game conditions improved more than children in the literacy game condition on measures of statistical understanding and arithmetic. Families who played graphing games used more number and math talk during play than families who played literacy games. Talk during play did not relate to gains in statistical understanding or math abilities.

These findings provide initial evidence on the effectiveness of games for promoting children's early statistical understanding, as well as descriptive information about children's early graphing skills and parent and child engagement in graphing games at home. Results also support the development of play-based interventions and materials to promote children's early mathematical and statistical skills, with implications for children's later development and achievement.

PROMOTING CHILDREN'S EARLY MATHEMATICAL AND STATISTICAL UNDERSTANDING THROUGH PARENT-CHILD MATH GAMES

by

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Table of Contents

List of Tables

List of Figures

.

Chapter 1: Introduction

Statement of the Problem

Basic statistical literacy is essential for understanding and making inferences from information received from external sources and for developing critical thinking skills necessary for engagement in real-world contexts. These skills are essential throughout the lifespan, as adults constantly consider data and sources when making decisions, such as what to buy, where to live, and how to vote. The foundation for these skills is built in early childhood, as data analysis is a central topic area in children's early mathematical development (National Council of Teachers of Mathematics, 2000).

Data analysis is an application of children's foundational math skills, including counting, numerical magnitude comparison, and arithmetic (National Governors Association, 2010). Understanding and interpreting data contextualizes numbers and mathematical relations and is important across academic subject areas, including math, science, reading, and social studies, as well as real-world experiences (Niezgoda & Moyer-Packenham, 2005; Van de Walle et al., 2018). Basic statistical literacy is also important for understanding and making inferences from information received from external sources and for developing critical thinking skills necessary for engagement in real-world contexts (Basile, 1999; Larson & Whitin, 2010). Early statistical understanding involves higher order thinking skills, as children learn how to ask and answer statistical questions and think critically about what is involved in the processes of developing and answering these types of questions (Cook, 2008; Glazer, 2011; Niezgoda & Moyer-Packenham, 2005; Van de Walle et al., 2018; Whitin & Whitin, 2003). These abilities to interpret and make inferences from graphs continues to be essential throughout the lifespan (Franklin et al., 2007; Sharma et al., 2010).

As data analysis is considered a central component of early math learning, yet one that is often not a primary focus of instruction in early grades (English, 2012; English, 2013), additional experience with data analysis and graphing in early childhood has the potential to enhance children's abilities from a younger age. Further, despite the lifelong importance of graphing skills and statistical literacy, research shows that middle school, high school, and college students struggle with interpreting and constructing graphs (Lapp & Cyrus, 2000; Leonard & Patterson, 2004; Padilla et al., 1986; Tairab & Al-Naqbi, 2004). These findings further highlight the importance of children having a strong foundation in their early graphing and data analysis skills. Specifically, developing engaging, effective methods for teaching early data analysis is important, as they have the potential to enhance children's development of statistical understanding and overall math abilities and provide them with a stronger foundation for continuing to develop their skills throughout their later schooling experiences and adulthood. In particular, prior research emphasizes the importance of active, meaningful practice with graphing skills (English, 2012; Glazer, 2011; Roth & McGinn, 1997) and considers the role of scaffolded discussions about graphing and data topics for children's learning (Lee & Francis, 2018; Russell, 2006). In considering active and engaging methods for promoting children's graphing and data analysis skills, the current study extends prior work on the role of games as an engaging method for math learning in early childhood, by focusing specifically on promoting children's early statistical understanding through a home-based graphing game intervention.

Games and play are prevalent in early childhood education settings as they provide an engaging context for early learning of social, emotional, and cognitive skills (Golinkoff et al., 2006). Accordingly, one increasingly popular method of teaching early math concepts is through playing games focused on math content, and many games have been developed both commercially and by researchers for children to play with their parents, teachers, and peers, with the aim of bolstering children's early mathematical knowledge, skills, and abilities. Math games are one way that children can learn math from parents, teachers, or peers in an engaging, motivating setting. Importantly, math games can simultaneously provide an opportunity for children to actively practice math and problem-solving skills and a context for parents and teachers to support children's learning by providing examples and feedback through play, thus providing a context for appropriate math instruction in early childhood which can make early math achievement attainable for all children, and has implications for later academic achievement (Clements & Sarama, 2011).

Although math games are often used in early childhood classroom and home settings, research on the effectiveness of math games often focuses on games designed for promoting children's numerical skills, and there is little research examining games targeting math concepts more broadly. The current study seeks to fill this gap by examining games targeting children's early graphing and statistical understanding. Understanding how games are effective across math content areas is important for children's development of early math skills, and has implications for the development of game-based math interventions to promote children's early math learning.

Background and Study Rationale

A strong foundation in math is essential for children's intellectual growth in math and other academic subjects throughout childhood and later development. Math learning in early childhood is especially important, as early math lays the foundation for later academic and mathematical achievement (Watts et al., 2014). In elementary school, children who begin kindergarten with higher math skills continuously show greater achievement in math in first, second, and third grades than children who enter elementary school with lower math skills (Jordan et al., 2009). In addition, children's math knowledge in preschool is predictive of their scores on state achievement tests throughout middle school (Fyfe et al., 2019) as well as of their academic and mathematical achievement through adolescence (Watts et al., 2014). Further, the relations between children's early math abilities and later academic success hold across other factors that have the potential to influence achievement, including socioemotional skills, executive functioning, gender, and income level (Duncan et al., 2007). Beyond academic outcomes, children's math ability in early childhood is also predictive of their socioeconomic status in adulthood at age 42, as defined by their occupation, housing, and income (Ritchie & Bates, 2013). Despite the importance of early math, there is still wide variation in children's math abilities at the start of kindergarten (Jordan et al., 2006). Because early math learning is critical for later success, developing engaging and effective methods for early math instruction are important.

In early math learning, play is important as it directly builds on young children's math interests and further incorporates math learning into their daily lives. The use of play and games to promote children's learning builds from classic developmental theories, including Vygotsky's sociocultural theory and Piaget's theories of cognitive development, which highlight the importance of developmentally appropriate instruction and adult guidance of children's learning (Vygotsky, 1986) as well as children's engagement in their own learning (Piaget, 1950). More recent playful learning theories describe games and play as an engaging context for learning social, emotional, and cognitive skills (Golinkoff et al., 2006; Hassinger-Das et al., 2017).

Building from the Science of Learning, it is argued that games provide a learning setting where parents or teachers can engage children in child-directed math instruction, as well as a context in which children are active and engaged, as gameplay allows children to directly practice and explore concepts in a structured, dynamic way (Zosh et al., 2018). Math games can provide an opportunity for children to actively practice math and problem-solving skills and a context for parents and teachers to support children's learning by providing examples and feedback through play in an engaging, motivating setting (Clements & Sarama, 2014; Sarama & Clements, 2012).

Studies specifically examining the role of games for children's math development have found that playing math games with parents, peers, or teachers can increase children's math knowledge in early childhood, and that even brief sessions (15-20 minutes) of gameplay can have a profound impact on young children's math skills. Game interventions have shown improvements with medium to large effect sizes in children's counting, numeral identification, magnitude comparison, number line understanding, and arithmetic skills as well as performance on standardized tests of math achievement. These results are consistent across numerical board games (Skillen et al., 2018; Whyte & Bull, 2008), card games (Loehr & Rittle-Johnson, 2017; Ramani & Scalise, 2020), and physically active games (Navarrete et al., 2018), as well as for children of varying levels of math ability (Siegler & Ramani, 2009), ages (Ramani & Siegler, 2008), and socioeconomic backgrounds (Ramani & Siegler, 2011). Studies also demonstrate that certain elements of games can be designed to facilitate more meaningful practice and interactions that lead to greater growth in children's math skills, including game board designs (Siegler & Ramani, 2009), game materials and structure (Chao et al., 2000), and the training and instructions provided to adults and children playing the games (Sonnenschein et al., 2016).

Further, research indicates that children benefit from parent math talk during gameplay at home, and that the quality and quantity of talk influences children's learning from games (Ramani & Scalise, 2020; Vandermaas-Peeler et al., 2012).

However, more research is needed to explore the breadth of the impact of games, as the majority of studies examining math games focus on games designed to promote children's numerical skills, such as counting (Laski & Siegler, 2014), magnitude comparison (Scalise et al., 2017), number line understanding (Elofsson et al., 2016), and arithmetic (Guberman & Saxe, 2000). While these areas of math are important, early math also comprises topics including algebra, geometry, measurement and data analysis, which along with number and operations, all fall under the umbrella of early problem solving (Ginsburg et al., 2008; National Council of Teachers of Mathematics, 2000; Sarama & Clements, 2008). More research is needed on the effect of games for math concepts in these other domains. Because of the importance of developing an early understanding of graphing and data analysis, the current study expands on prior research on math games by examining the use of games for promoting children's graphing skills and statistical understanding.

Current Study

The goal of the current study was to examine the effectiveness of games for promoting children's early understanding of graphing and data analysis in a home-based family math game intervention. Specifically, the study examined if graphing games can promote children's early statistical understanding, if different types of games promote learning differently, and what types of parent input during gameplay promote gains in children's learning.

The games used in the current study were designed to promote children's early understanding of graphs by providing engaging, direct practice with two foundational concepts related to graphs—making graphs and interpreting information presented in graphs (Franklin & Mewborn, 2008). The graphs included in the games put numbers into familiar contexts that are relevant across subject areas and life experiences, including graphs about favorites (e.g., foods, books, sports), family size, weather, and going to the zoo, among other topics. Focusing graphing on these familiar contexts allows children to further develop their math skills by making connections between their numerical skills (e.g., counting, magnitude comparison, arithmetic), and applied contexts for problem solving that build on their natural interests (Basile, 1999).

Aims and Hypotheses

Aim 1a. Does playing graphing games lead to improvements in children's statistical understanding and math abilities? Graphing and statistical understanding are an application of children's numerical skills, including counting, magnitude comparison, and arithmetic. One method for promoting children's skills in these areas is through games. According to both the theoretical frameworks of Playful Learning (Fisher et al., 2010) and the Science of Learning (Zosh et al., 2018) as well as empirical work, math games can promote learning in multiple ways. Specifically, math gameplay can provide direct practice with concepts, involve multiple, redundant cues to the concepts, physical representations of the concepts that align with children's developing mental representations, and feedback to reinforce these concepts. Further, these are provided within a game context that is structured to promote these skills specifically through the design of game materials and the actions involved in playing the game. Through these mechanisms, games for children's math skills, including counting, magnitude comparison, and arithmetic have been shown to be effective. As games have been shown to effectively promote math learning in these areas, it was expected that games would also be effective for promoting children's abilities to interpret and construct graphs in the same ways. In particular, the games were developed to provide specific, direct practice with key elements of graphing (e.g., comparing magnitudes of categories, constructing graphs based on data) through the game board design and actions of playing the game, which involve repeated cues to the concepts, physical representations of concepts, and feedback. The specific features of the card games and board games that are designed to promote learning are delineated in Chapter 3. Further, as graphing involves applications of math skills, such as arithmetic and magnitude comparison, it was expected that playing graphing games would also promote children's abilities in these areas.

Aim 1b. Does playing a board game versus a card game lead to differences in improvements in children's statistical understanding? According to the Cognitive Alignment Framework, games can promote learning through the alignment of the physical representations of concepts and actions of gameplay with children's developing mental representations of the concepts (Laski & Siegler, 2014). Consistent with this theory, prior research indicates that game structures providing more direct practice with relevant math content (e.g., linear versus circular board games for linear number line understanding) are known to promote math learning more. Drawing from this theoretical and empirical work, it was expected that gains in statistical understanding would differ based on the type of game played due to features of the games themselves and the corresponding practice they provide. In the current study, each graphing game's design included specific features that were expected to promote children's abilities to interpret graphs (card game) and construct graphs (board game). The specific features of the current games that were designed to promote learning are described further in Chapter 3. As these features were specific to each game type, it was expected that the different game types could promote learning differently.

Aim 2. Does the mathematical and statistical talk parents and children use during play relate to gains in children's statistical understanding and math abilities? A critical component of theories of playful learning is that the interactive and engaging components of play and games promote children's learning. One measure of engagement and interactivity during gameplay is the type and amount of talk that parents and children use during play. Research indicates that the quality and quantity of math talk that parents use with children relates to their math learning (Levine et al., 2010; Elliott et al, 2017; Ramani et al., 2015). For math games specifically, studies have shown benefits of parent math talk during gameplay for children's learning (Ramani & Scalise, 2020; Vandermaas-Peeler et al., 2012; Vandermaas-Peeler & Pittard, 2014). Accordingly, in the current study it was expected that variation in parent math and stats talk would relate to children's learning. Specifically, it was expected that more frequent use of mathematical (e.g., number words, words related to mathematical operations) and statistical (e.g., words related to statistics and graphs) talk would relate to greater gains in children's understanding.

Contribution and Impact

The current study contributes to the field by providing initial evidence on how games can promote children's early understanding of graphs and data analysis, which are a critical part of children's early numerical understanding. Early data analysis and measurement skills put numbers and numerical operations into real-world contexts that are relevant across disciplines, and the ability to interpret and make inferences from graphs continues to be essential throughout the lifespan. Games play an important role in children's early math development, both in school and at home. Research to date on the role of math games for children's learning has primarily examined games for children's numerical skills, and there is limited work on the role of games in other areas of mathematical development, including early data analysis. Results from the current study will provide evidence on the role of games to further engage and promote children in their learning of these essential skills.

The study also lays the groundwork for future studies of the use of games for statistical understanding, including the use of play-based methods for statistics instruction in elementary school classrooms. Because early understanding of data analysis is important for children's mathematical development across disciplines, developing engaging and effective methods of instruction, such as games, is important.

In addition, the proposed study has applications for increasing family engagement in math at home. By providing children and parents with graphing games they can play at home, the current study has the potential to increase children's early math achievement and family math engagement through brief, game-based parent-child interactions. Because early math skills relate to later academic achievement, promoting children's math development in early childhood is essential.

Chapter 2: Review of the Literature

Overview

This section will review theories on games and playful learning, influences on math learning relevant to the context of gameplay, and the research to date on the role of games in children's math learning. Review of the research to date will focus specifically on three questions regarding the effectiveness of math games for children's math learning. First, when and what games are effective for children's math learning? Second, do individual child characteristics lead to differences in children's learning from games? Third, what makes games effective for children's math learning? Finally, gaps in the literature will be identified and discussed, including the effectiveness of math games for mathematical content beyond numerical concepts and the impact of game type on children's math learning.

Theoretical Background

The use of play and games to promote children's learning builds from classic developmental theories, including Vygotsky's sociocultural theory (Vygotsky, 1986) and Piaget's theories of cognitive development (Piaget, 1950). A central tenet of Vygotsky's theory is the importance of developmentally appropriate instruction for children. Adults scaffold children's learning by providing instruction tailored to a child's zone of proximal development—the space between a child's current ability level and the ability level they can attain with appropriate guidance from an adult (Vygotsky, 1986). Parents and teachers can use math games to scaffold children's learning by systematically guiding children to a new learning outcome through elements of the game. This scaffolding could include a counting strategy for moving spaces ahead on a game board or providing prompts and feedback for math skills that children use in the game.

Learning, therefore, relies on engagement from both the child and the adult guiding them, as the adult needs to observe the child's current and developing abilities and tailor guidance appropriately (Winsler, 2003). Games provide a learning setting where parents or teachers can engage children in math content within their zone of proximal development. Studies show that these adults are able to determine children's developing abilities and adapt guidance appropriately while playing games with them (Bjorklund et al., 2004; Rogoff et al., 1984).

Piaget's theory also highlights the importance of children's engagement in their own learning. Children must be active agents in their own cognitive development, and their learning depends on their engagement (Piaget, 1950). Games constitute a context in which children are active and engaged, as gameplay allows children to directly practice and explore concepts in a structured, dynamic way. Piaget also emphasizes the role of peers for children's learning. Through interaction with peers, children are actively engaged in their own learning, which further facilitates children's development (Tudge & Rogoff, 1989). Games allow for this type of learning to occur as they facilitate children's active engagement in a learning activity with peers or other players.

Together, these theories lay the groundwork for considering children's early math development through the lens of playful learning, as play and games provide a setting for child-directed math instruction where children are actively engaged in their own learning with adults and peers.

Games and Playful Learning

Play and games provide an important context for early learning and serve as a vehicle for promoting the development of young children's social, emotional, and cognitive skills (Golinkoff et al., 2006). Building from both the Science of Learning and theories of Playful Learning, it is argued that games provide a learning setting where parents or teachers can engage children in child-directed math instruction, as well as a context in which children are active and engaged, as gameplay allows children to directly practice and explore concepts in a structured, dynamic way (Fisher et al., 2010; Hassinger-Das et al., 2017; Zosh et al., 2018).

When considered in the context of the Science of Learning, types of play and instruction can be viewed as a spectrum of playful experiences, which vary in who play is initiated and directed by (e.g., children or adults) as well as if a learning goal is involved (Zosh et al., 2018). The spectrum includes free play, guided play, games, co-opted play, and playful instruction. Free play involves voluntary, child-initiated and child-directed play, has no specific learning outcome associated with play, and is typically a child playing alone or with other peers (Fisher et al., 2010; Rubin et al., 1976; Sutton-Smith, 2001). Children can learn from free play; however, the content of their learning is a product of their own exploration and engagement. Guided play is more structured than free play, and has specific learning outcomes associated with the play. Specifically, guided play is child-directed, but it typically is adult-initiated and involves adults scaffolding children's learning of outcomes through the play (Fisher et al., 2010; Hirsh-Pasek et al., 2009; Weisberg et al., 2016). Adults provide guidance, which targets children's attention during play and promotes their learning of specific concepts in a directed but playful way. In contrast, co-opted play is child-initiated but adult-directed. This often occurs when an adult interrupts or changes the focus of the play the child is engaging in, and does not necessarily constitute playful learning for the child (Zosh et al., 2018). Finally, playful instruction is both adult-initiated and adult-directed.

Accordingly, in the Science of Learning perspective, games fit between guided play, adult-directed play, and playful instruction, as games are initiated by adults, directed by children, and contain a specific learning goal (Zosh et al., 2018). Consequently, games provide a learning setting in which parents or teachers can engage children in meaningful child-directed instruction and social interactions, as well as a context in which children are joyful, active, and engaged, as gameplay allows children to directly practice and explore concepts in a dynamic, structured way.

While play and games both contribute to children's learning, it is important to distinguish what constitutes a game versus play. Games are a type of playful learning, and they include all the elements of free play and guided play in that they allow for child agency, are engaging, and support children's learning in an active, structured way (Hassinger-Das et al., 2017). What separates games from other types of play is that they include more concrete and directed goals and a formal rule structure (Hassinger-Das et al, 2017; Rubin et al., 1983). The inclusion of rules is a critical distinction between play and games. In order to play a game, players must have the same end goal in mind and follow the same set of rules to achieve that goal.

In the case of learning games, the game is designed to facilitate players' learning of certain concepts through aspects of the game itself, such as repeated practice with math skills, and through aspects of the social interactions involved in gameplay, such as guidance or feedback from other players. The targeted and structured nature through which learning is attained through following the rules of the game also separates games from other forms of play, which may target concepts in a less systematically structured way.

Playful learning theories also contrast play and games with direct instruction—a teaching method where learning is adult-directed and concepts are directly taught, as opposed to being discovered through play or games (Hassinger-Das et al., 2017). The playful learning framework posits that learning through play, games, and direct instruction are all valid instructional methods for early childhood learning, and that different types of content may be learned best from different forms of instruction. While direct instruction imparts content in the most structured way, learning through play and games may be more engaging for students, as play and games are interactive and fun (Ilgaz et al., 2018). This is especially important for maintaining students' motivation to learn.

In the context of early math learning, play and games are important as they directly build on young children's math interests and are a way to further incorporate mathematical learning into their daily lives. Early math comprises topics involving number and operations, algebra, geometry, measurement and data analysis, which all fall under the umbrella of early problem solving (Ginsburg et al., 2008; National Council of Teachers of Mathematics, 2000; Sarama & Clements, 2008). Research has shown that children naturally explore these topics through counting, sorting and making categories and patterns, and making comparisons when engaging in free play (Ginsburg, 2006; Sarama & Clements, 2009; Sarama & Clements, 2012). This indicates that children have a natural interest in the mathematical properties of their environment and use play as a way to explore them. By engaging in play with children, parents and teachers can use these naturally occurring math experiences to further develop children's math interests and skills by providing guidance or scaffolding to the specific math content.

Games can also provide a setting for learning that situates math concepts in a context, in contrast to direct instruction where concepts may be presented in a decontextualized way, which is less engaging or motivating for students (Taylor-Cox, 2009). This is not to say, however, that games are diametrically opposed to direct instruction. Games can be used to complement concepts taught via direct instruction, to further contextualize and motivate students (Clements & Sarama, 2014; Sarama & Clements, 2012) and to practice engaging in mathematical thinking and problem solving (Fisher et al., 2012). In this way, games are a way to further enhance math learning in a way that is enjoyable and effective.

The importance of games and play for children's early math learning is supported by research on the home math environment, which examines the extent to which children's experiences at home include formal or informal math activities. Studies examining children's home math environment often include games as a part of the landscape of opportunities children may have to learn math at home. As the home math environment is known to relate to children's concurrent and later math outcomes (Ramani & Siegler, 2014), there is potential for math games to contribute to children's early math development. In fact, children's engagement in math games at home as preschoolers and kindergartners has been shown to relate to their concurrent math skills and predict their informal and formal math skills longitudinally through first grade (Niklas & Schneider, 2014; Zhang et al., 2020). More specifically, studies have found that the frequency of gameplay relates to children's calculation skills (Mutaf Yildez et al., 2018), non-symbolic arithmetic (Skwarchuck et al., 2014), spatial span, math knowledge, and single-digit addition fluency (LeFevre et al., 2009), counting and knowledge of number-related information (Benavides-Varela et al., 2016).

Beyond the home environment, there is also evidence that incorporating games into learning at school can help children develop math skills. Math curricula that include game-based instruction have been shown to lead to improvements in children's math learning in preschool

(Clements & Sarama, 2007), preschool through grade 2 (Griffin, 2004), and grades 2 through 5 (Wendt et al., 2014). A review of games and classroom learning found that use of math games in elementary school and middle school improved children's math learning as much or more than typical math instruction (Randel et al., 1992). More recent work has also identified games and play-based learning as instructional methods that align with instructional standards such as the Common Core State Standards Mathematics Standards for all elementary school grades (Ramani & Eason, 2015; Zosh et al., 2016).

Review of Research on the Role of Math Games for Math Learning

Overview

Research to date was reviewed with the aim of examining three questions related to children's math learning from math games: 1) When and what games are effective for children's math learning? 2) Do individual child characteristics lead to differences in children's learning from games? 3) What makes games effective for children's math learning? The synthesis of the present research in these areas allows for further evidence-based design and use of math games to enhance children's learning.

Studies discussed in this section include peer-reviewed journal articles examining an early childhood sample, defined as preschool through grade 3 (ages 3 to 9 years old). The current review specifically focuses on articles examining math games and math outcome measures. In order to understand impacts on math learning, studies including games administered as part of a larger curriculum or intervention were not included. As curricula and larger scale interventions typically include multiple elements, such as games, books, and other learning activities, it is not possible to distinguish the effect of the games themselves on children's outcomes from the effects of other elements of the curricula or interventions.

In addition, as the focus of the current study is on traditional games, only studies examining traditional games are discussed here. Studies examining digital or electronic games were not considered, because digital and electronic games can provide a different type of instructional setting for children's learning than traditional games. There is more variability in the context of digital gameplay, as children may be more likely to play these games individually, versus playing with parents, peers, or teachers. Further, when children do engage in digital games with others, the social context of gameplay may be different, leading to differences in the quality of learning interactions players have during gameplay (de Vries et al., 2021; Zosh et al., 2015). While electronic games can be designed to provide programmed feedback to children (Ramani et al., 2019), this is not equivalent to an adult providing prompts and feedback targeted specifically to that child's zone of proximal development. Because of these differences, digital and electronic games did not fit into the aims of the current study.

In addition, it is also important to distinguish math games from researcher-administered math tasks (with or without gamified elements). While certain math tasks may be presented or introduced to children as a game, possibly to increase engagement or enjoyment, tasks were not considered games unless they truly fit into the framework of playful learning activities as described above and had a rule structure and determined outcome.

Overall, of the 23 articles reviewed, 20 were experimental studies and three were correlational studies. Three studies were conducted in a single time-point, and 20 were longitudinal intervention studies (see Table 2 for a summary of dosage of gameplay). Sixteen studies examined preschoolers, and seven studies examined children in kindergarten through grade 4. Eleven articles included games targeting basic number skills, and 12 articles included games targeting more advanced number skills, such as decimals or magnitude comparison. Seventeen studies examined games played at school, and six studies examined games played at home. Table 1 provides a summary of participant ages and game characteristics.

When and What Games Are Effective?

When examining when and what games are effective for children's math learning, it is important to consider both the physical and social contexts of gameplay as well as the type and content of games played. Studies of these areas include studies of games played at home and at school, and studies of board games, card games, and physical or other games. Table 1 provides a summary of the game type, content, and context for each study as well as the age of children playing the games, and Table 3 provides a summary of the math outcome measures included in each study.

Context of Gameplay

The context of gameplay was defined both by the location of play (e.g. home, school) and the social partners engaged in play (e.g., parents, peers, teachers, experimenters). Five studies examined games played at home, and in all of these articles, children played games at home with their parents. Nineteen studies examined games played at school. Of these, 13 studies examined games played with an experimenter, and six examined games played with others (e.g., teachers, paraprofessionals, peers, or parents). However, none of the articles specifically examined the role of the context of gameplay in an experiment comparing the effect of different contexts on children's math learning. Thus, no inferences can be drawn about the specific role of context of gameplay for children's math learning.

Generally, all articles indicated that games played resulted in positive math outcomes for children, indicating that children learn from play in various social contexts, including play with experimenters, peers, teachers, and parents. Specific details of the methodology and findings of these studies will be elaborated in later sections. Findings also indicated that non-researchers (parents, teachers, and paraprofessionals) are capable of administering researcher-developed games in a way that is engaging for children and meaningful for their academic learning. This is important, as impacts of games on children's math learning are less meaningful if they cannot eventually be translated into real-world, applied settings such as homes and classrooms.

Game Type and Content

Games studied were classified into three categories: (1) board games, (2) card games, and (3) physically active games or sets of games comprising multiple types of games. These games were further broken down by the math content included in the gameplay and classified as games targeting basic number skills or games targeting advanced number skills. Games for basic number skills included games about numbers under ten, and games for advanced number skills included games about numbers greater than ten, as well as games targeting other advanced math concepts including base ten understanding, magnitude comparison, arithmetic, and decimals. All of the games for basic skills were implemented with preschool-aged children, while games for advanced number skills were implemented with all ages, ranging from preschool through fourth grade.

Board Games. ***Basic Number Skills.*** Seven articles examined the effects of two basic numerical board games. Five articles studied The Great Race, a 1-10 researcher-developed numerical board game (Ramani & Siegler, 2008; Ramani & Siegler, 2011; Ramani, et al., 2012; Siegler & Ramani, 2008; Siegler & Ramani, 2009). Two articles studied The Ladybug Game, a commercially available numerical board game (Vandermaas-Peeler et al., 2012; Vandermaas-Peeler & Pittard, 2014).

The Great Race is a horizontal linear board game where players spin a spinner with the numerals 1 and 2 to see how many spaces to move on each turn. Each space contains a numeral from 1 to 10, and spaces are ordered numerically. The Great Race was designed to promote children's understanding of numerical magnitudes by providing children with multiple, redundant cues to number within their gameplay. For example, the design of the game board promotes a linear representation of number by showing the numbers arranged in a line and evenly spaced. This is additionally cued as children take their turn during the game, as the values of numbers are represented in the number of spaces children move their tokens and the numbers (and number of numbers) they say while moving their token (Siegler & Ramani, 2008).

Siegler and Ramani (2008) compared children who played The Great Race to children who played a version of the game where each game space had different colors but no numbers. Preschool children from lower-income backgrounds played the game at their schools with an experimenter for four sessions over two weeks. Results indicated that children who played the numerical game improved more on a 0 to 10 number line estimation task than children who played the color version of the game, with a moderate effect size.

In a related study, Ramani and Siegler (2008) also used the numerical and color versions of The Great Race in a study to examine the benefits of playing the number game on several numerical skills and whether the benefits lasted even after not playing the game for several weeks. Preschoolers played the game at their schools with an experimenter in four sessions over two weeks. Findings replicated improvements on the 0 to 10 number line estimation task for children playing the number version of the game. In addition, children who played the number version of the game also improved more than children who played the color version of the game on numeral identification of the numbers 1 to 10, verbal counting from 1 to 10, and magnitude comparison of pairs of numbers 1 to 9. These benefits were also stable for at least two months. Effect sizes were moderate for number line estimation, counting, and number identification and large for magnitude comparison.

In a subsequent study, Siegler and Ramani (2009) further examined how gameplay related to children's math skills by comparing children who played the linear, horizontal version of The Great Race, children who played version of the game where the numbers were presented on spaces arranged in either a clockwise or counterclockwise circle, and a control group of children who did numerical activities including counting, numeral identification, and counting objects. Preschoolers completed games or activities with an experimenter at their school in five sessions over three weeks. Outcome measures included counting 1 to 10, numeral identification of numbers 1 to 10, 0 to 10 number line estimation, magnitude comparison of pairs of numbers 1 to 9, and arithmetic word problems with addends 1 to 4.

Results indicated that both linear and circular games led to greater improvements in children's number line estimation and numeral identification than the numerical activities control group. However, for number line estimation, children who played the linear version of the game improved more than those who played the circular version of the game. Similarly, children who played the linear game also showed increases in magnitude comparison and arithmetic, while those who played the circular game or numerical activities did not improve. Effect sizes were large for children who played the linear game. There were no differences in counting, as all groups were at ceiling at pretest. These findings demonstrate that the linearity of the board game is critical for promoting children's numerical skills, and is in line with the proposed mechanism of the linear game's redundant cues to numerical magnitudes enhancing children's learning from the game.

In one study, Ramani and Siegler (2011) also compared the linear and circular versions of The Great Race to a numerical activities control group. Preschoolers played the game or completed activities at their schools with an experimenter in four sessions. Results indicated that both games led to improvements of moderate effect size in children's 1-10 numeral identification and simple arithmetic. For 0-10 number line estimation, children who played the linear board game improved more than children who played the circular game or completed numerical activities. A large effect was found for children's magnitude comparison, which improved more for older than younger preschoolers across game or activity groups. And there were no differences in counting, as all groups were at ceiling at pretest.

A second study compared results of playing the linear board game for samples of middle-income (Ramani & Siegler, 2011) and low-income (Siegler & Ramani, 2009) preschoolers. Results indicated that low-income children improved more than middle-income children on number line estimation, magnitude comparison, and arithmetic. Effect sizes were large for low-income children, and moderate for middle-income children. Both income levels improved at numeral identification. And there were no differences in counting, as both groups were at ceiling at pretest.

Finally, Ramani and colleagues (2012) examined the effects of the linear number and color versions of The Great Race when preschoolers played at their schools in groups led by an experimenter in one study and led by a paraprofessional in a second study. Games were played over 3-4 weeks in four sessions. In both studies, playing the number version of the game improved children's 1 to 10 counting, 1 to 10 numeral identification, 0 to 10 number line estimation, and magnitude comparison with numbers 1 to 9, with small to medium effect sizes. These findings are important as they demonstrate that children can learn from the game when they play with other children and when they play with non-researchers. This means that the effect of the game on children's learning can be translated to settings other than a research context.

The Ladybug Game is a commercially available number board game that involves moving spaces along a path to help a ladybug get home. Players draw cards with written numerals indicating the number of spaces to move each turn, and throughout the game they collect cards with quantities of aphids (shown on cards both as written numerals and a quantity of circles containing pictures of aphid characters).

Both studies using The Ladybug Game were of preschoolers playing the game with their parents. In both studies, the authors expected that parent guidance during gameplay would be the primary mechanism that promoted children's learning from the game, as prior research had shown variation in parent guidance and relations of parent guidance to children's math learning. Vandermaas-Peeler and Pittard (2014) examined a single time-point of gameplay where parents and children played together at children's preschools, outside of school hours. Vandermaas-Peeler and colleagues (2012) examined gameplay over a two-week intervention period where children and their parents played together at home. Results of both studies demonstrated that parent guidance during gameplay related to children's math learning as measured by the Test of Early Mathematics Ability (TEMA), which includes items related to children's understanding of symbolic and non-symbolic number, counting, arithmetic, and magnitude comparison (Ginsburg & Baroody, 2003).

Advanced Number Skills. Seven articles examined the effects of playing board games for improving children's advanced number skills. Three of these articles considered different types of 10x10 grid board games with numbers from 0 or 1 to 100. These games involve spinning a spinner and moving a corresponding number of spaces with the goal of reaching the 100 space first. The proposed mechanism for learning from these types of board games is the cognitive alignment framework (Laski & Siegler, 2014), which posits that children are able to learn more when the game materials are more closely aligned to developing mental representations of number and numerical relations. In this way, using a 10x10 game board provides an explicit base ten structure, with a linear structure within each decade. Further, when children count on (e.g., count up and say the numbers of the spaces they are on), this reinforces children's understanding of the numbers from 0 to 100 as well as their relative positions and magnitudes.

Skillen and colleagues (2018) examined kindergartener's play of the Number House game, which is a 10x10 grid game with an "elevator" column next to the spaces with numbers with a 5 in the ones place, which holds an equivalent role to the ladders in *Chutes and Ladders*. Children played the game at school with an experimenter during four sessions over four weeks. Findings indicated that the Number House game related to kindergartener's improvements on a standardized math test measuring children's forward and backwards counting skills, precursor and successor number knowledge, numeral identification, quantity comparison, quantity parts and composites, seriation, and addition and subtraction. Improvements were greater for children who played the game with a count on versus a count from one procedure. Overall, effect sizes were large for children who played the game with a count on procedure, with larger effects for subsections of the test examining counting skills and moderate effects for subsections examining the more advanced math skills.

Similarly, Laski and Siegler (2014) examined kindergartener's play of Race to Space at school with an experimenter in four sessions over three weeks. They found that playing this 10x10 grid board game with a count on (i.e., count up from the number of the current space on the game board) versus a count from one procedure led to kindergartener's improvement in 0 to 100 number line estimation, numeral identification of numbers ranging from 0 to 100, and counting on from single or two-digit numbers. Reported effect sizes were large for counting and moderate for all other measures.

In two studies, Sonnenschein and colleagues (2016) examined the effects of commercially available games. In one study, they compared children who played *Chutes and Ladders* and children who played *Candy Land*. Games were played at home with parents over a five-week intervention period. Results indicated that both games led to improvements in preschooler's counting and 1 to 10 numeral identification making it difficult to determine whether the games were beneficial to children's math skills or whether there was a general growth in knowledge during this period. There were no improvements in magnitude comparison as both groups were at ceiling at pretest. In a second study, they examined just *Chutes and Ladders* with different parent training conditions. They found that all conditions improved on numeral identification. For 0 to 10 number line estimation, the group that received stickers and parent training improved more than the other groups; however, when restricted to a sample of children who demonstrated understanding of the number line estimation task, all training conditions improved. This indicates that beyond parent input, children's own math abilities may influence their learning from math games.

Three articles examined board games displaying numbers either linearly or circularly.

Two of these studies examined game interventions where game materials increased in increments from 1 to 40 over the duration of the intervention.

Elofsson and colleagues (2016) used linear and circular games that increased to include an additional decade of numbers over sessions, with one session each of 1-10 and 1-20 materials, and two sessions each of 1-30 and 1-40 materials. Children in control conditions either played non-linear number activities or games, such as *Memory*, *Bingo*, or *Go Fish*, or did not play any games or activities. All sessions were played at children's preschools with an experimenter. The use of linear number games was based on the theories discussed above that the practice children get through playing linear games specifically maps onto their development of a linear mental number line. Findings indicated that the linear versions of these games led to medium effect size increases in preschooler's 0 to 10 number line estimation and arithmetic including simple and complex addition and subtraction. Both games led to similar, non-significant improvements in counting forwards and backwards. And children who played the circular game improved more on naming numbers (including a subset of numbers 1 to 99) than children in either control group.

Similarly, Whyte and Bull (2008) considered a linear game that displayed ten numbers. These numbers changed over the duration of a four-week intervention such that each week focused on a different decade (e.g., 1-10, 10-20, 20-30, 30-40). A comparison group played a numerical magnitude comparison card game which also increased in numbers over the four weeks. A linear board game was used because the structure of the board game itself is expected to provide children with cues to the linearity and spatial relations of numbers, and therefore enhance children's number line estimation abilities. Children played games at their preschools in groups of 3-4 students with an experimenter. Results indicated that both games led to improvements in preschooler's counting objects up to 20, number naming and magnitude understanding with numbers 1 to 9, and 0 to 10 number line estimation. Improvements for number line estimation were greater for children who played the linear board game.

In addition, Cheung and McBride (2017) investigated a 1 to 30 horizontal board game that kindergarteners played at home with their parents over a four-week intervention. They included a condition where parents received training on what guidance to provide during the game, as well as a condition where parents did not receive any training, as it was expected that parent numeracy guidance would promote children's learning above and beyond their learning from the game itself. They found that playing the game led to increases in kindergartener's forwards and backwards counting, numeral identification of two- and three-digit numbers, and simple and complex addition abilities for children who played with parents who had completed game training. For counting, effect sizes were large for children whose parents had received training on the game, and medium for children whose parents did not receive training. For all other measures, effects were small for both training and no training conditions.

Finally, one study (Guberman & Saxe, 2000) examined Treasure Hunt, a game for base ten and place value understanding and arithmetic skills, which third and fourth grade students played at school with a peer. By creating scenarios within the game context that require children to solve arithmetic problems to progress in the game, the game provides children with practice solving problems both individually and as a group, which allows for the development of problem-solving skills and strategies. Results showed that third grade students improved solutions to arithmetic problems, and students who played with older students also increased their use of more sophisticated arithmetic strategies.

Card Games. ***Basic Number Skills.*** One study examined a card game for basic number skills. Scalise and colleagues (2018) included a 1-10 number matching card game as a control comparison to a magnitude comparison card game, which is described further below. Children played the games at school with an experimenter in four sessions over three weeks. Results indicated that all preschoolers improved their counting 1 to 10, numeral identification of numbers 1 to 10, and non-symbolic magnitude comparison skills including non-symbolic quantities 4 to 15, regardless of game played. Children did not improve on non-symbolic ordinality with number 1 to 7. Children's symbolic magnitude comparison skills with numbers 1 to 9 also improved although not as much as those of children who had played the magnitude comparison card game.

Advanced Number Skills. Five articles included a card game for improving children's advanced number skills. Cheung and McBride-Chang (2015) examined a number sense card game for children ages 1.5- to 6-years-old. Children played the game at home with their parents over a ten-week intervention period. Cards showed a set of animals on one side and numerals on the other side, with numerals for the total number of animals as well as the number of each type of animal depicted on the other side (e.g., 7 animals, 6 monkeys, 1 giraffe; Cheung & McBride-Chang, 2015). Cards included numbers 0-10 and 10-20. The authors state that they selected numerical card games specifically because they are motivating and include multiple numerical representations which can promote children's understanding of numbers and abilities to use numbers. They found that children improved on numeral identification of a subset of numbers 1 to 99, object counting of sets sizes 4 to 20, rote counting on, identifying a missing number in a string of consecutive numbers, numerical magnitude comparison including numbers 1 to 42, and single-digit addition. Effects were large for all measures.

The remaining four articles examined numerical card games played like the card game "War," prompting practice of numerical magnitude comparisons. Two of these articles used numerical card games specifically because cards can provide both symbolic (e.g., numerals) and non-symbolic (e.g., dots or shapes) representations of number. These multiple representations of number on the cards are hypothesized to promote children's numerical understanding and early math skills (Ramani & Scalise, 2020; Scalise et al., 2017).

Scalise and colleagues (2018) found that playing a magnitude comparison card game with numbers 1-10 led to improvements in preschooler's counting 1 to 10, numeral identification of numbers 1 to 10, and symbolic (numbers 1 to 9) and non-symbolic (quantities 4 to 15) magnitude comparison abilities. However, improvements were only greater than those from a 1 to 10 matching card game for children's symbolic magnitude comparison skills, for which a large effect was detected.

Similarly, Ramani and Scalise (2020) compared a 1-10 numerical magnitude comparison card game to a shape and color matching card game. Children played at home with their parents over a six-week intervention period. Findings indicated that the amount of time families played the magnitude comparison game related to increases in preschooler's magnitude comparison of numbers 1 to 9 and their 0 to 10 number line estimation. Time spent playing the game did not relate to children's counting 1 to 25, numeral identification of numbers 1 to 10, and cardinality for sets ranging 1 to 10.

Whyte and Bull (2008) examined play of a magnitude comparison card game over a four-week intervention. The game was used as a control game for a linear board game, described above. The numbers presented on the cards increased over the duration of the intervention such that each week included an additional 25 numbers (e.g., 1-25, 1-50, 1-75, 1-100). Results indicated that preschoolers improved on counting objects up to twenty, as well as number naming and magnitude comparison with numbers 1 to 9. Children's 0 to 10 number line estimation also improved; however, improvements were less than those of children who played the linear board game.

Loehr and Rittle-Johnson (2017) examined a magnitude comparison game for older children, focusing on the comparison of decimal values. Third and fourth graders played the game at school with an experimenter. The game was proposed to help children's learning of decimal magnitudes by providing children with labels for decimal values that could aid their mapping of decimals to their base ten place value and whole number knowledge. Results indicated that students playing the game with formal decimal labels performed better for magnitude comparisons made during the game, decimal comparisons, and place value knowledge, and that children who played the game with no labels performed better on 0 to 1 decimal number line estimation. The authors reported large effect sizes for differences in in-game magnitude comparisons, and small effect sizes for number line estimation and decimal comparison abilities.

Physical/Other Games. ***Basic Number Skills.*** For basic number skills, one article considered a physical game, and two articles considered sets of games. Navarrete and colleagues (2018) examined a 1-10 embodied number line game for preschoolers. Children played the game at school as a class with an experimenter during six sessions over two weeks. The game was set up such that the life-size number line was positioned in the center and children were seated on either side of it. Children on one side viewed the number line in a spatially aligned way (e.g., numbers increasing from left to right), and children on the other side viewed the number line in a spatially misaligned way (e.g., numbers increasing from right to left). It was hypothesized that if only linearity practice was necessary for children's development of numerical understanding, then either perspective would promote children's learning; whereas if both linearity and spatial alignment were necessary, then only the spatially aligned perspective would promote children's learning.

Results indicated that playing the game related to medium effect size improvements in children's 1 to 10 counting and numeral identification of numbers 1 to 10, and large effect size improvements in 0 to 10 number line estimation, with improvements in number line estimation greater for children who played a spatially aligned game than those who played a spatially misaligned game. Children also improved at numerical magnitude comparisons with numbers 1 to 9, however these improvements were not different than those of children who did not participate in the math game intervention.

Van Herwegen and colleagues (2017) examined a set of eight games targeting approximate number system (ANS) ability for preschoolers. These games were played at school with an experimenter and included quantity guessing games, number comparison games with non-symbolic number, objects, and sounds, and action repetition games. The games were designed around non-symbolic number, because previous research had shown evidence of non-symbolic magnitude training improving ANS abilities in older children and adults. Results indicated that gameplay related to increases in children's ANS abilities with a large effect size.

Dillon and colleagues (2017) examined a math games curriculum that included games targeting non-symbolic number, one-to-one correspondence, and simple geometric shapes. These games were played at children's preschools with an experimenter, and included card games, sorting games, physical games, and board games. These games were expected to improve children's math abilities by providing children with early, informal experiences they wouldn't otherwise have to practice and develop these skills. Results indicated that math games related to increases in children's non-symbolic and symbolic math abilities as well as their geometry skills, including shape naming.

Advanced Number Skills. For advanced number skills, one article considered a physical game, and one article considered a set of games. Jirout and colleagues (2018) examined a physical spatial scaling game for children in kindergarten through second grade, which involved using a map to locate a star on a life-size grid search space. The game was played at school with an experimenter. Because spatial scaling abilities are known to relate to understanding of relative magnitudes, the authors expected that playing their spatial scaling game could enhance children's abilities on a task involving relative magnitude understanding, such as the number line estimation task. Results indicated that spatial scaling related to children's 0 to 100 number line estimation, and that boys performed better than girls in locating the star on the first try.

Chao and colleagues (2000) examined a set of games targeting number, addition and subtraction, and special numerical relations related to 5s and 10s. It was expected that the structure of 5s and 10s of the physical game materials would specifically promote children's abilities to solve problems with 5s and 10s, as the physical materials with this structure would help children to develop a mental image they could use during problem-solving. The games were facilitated by children's teachers and included card games, board games, and physical games. Results indicated that playing the games improved kindergarten students' performance on numerical interference tasks, backwards number sequence, addition strategies, subtraction, and understanding of special number relations for numbers with fives and tens.

Summary. These studies indicate that children can learn many math skills from a variety of types of games, including both researcher-developed games as well as commercially available games. Board games, card games, physically active games, and sets of games can lead to improvements in children's basic and advanced number skills. This indicates that the benefit of games on children's math learning is not limited to a specific type of game or games targeting a specific level of math content (e.g., basic or advanced). It is also important to note that while many of the studies focus on games for preschool and kindergarten children's math learning, there is also evidence of older elementary school children learning from games as well. This is important because it demonstrates that games can continue to facilitate children's learning of math content throughout children's development, even as that content becomes more advanced.

Do Individual Child Characteristics Lead to Differences in Children's Learning from Games?

As children bring different characteristics to their gameplay experiences, it is important to consider if math game play results in equal learning benefits for all children or if certain subgroups of children might learn differently than others from math game play. While there is limited work on this, a few studies have examined differences based on math ability level, age, SES, and gender.

Math Ability Level

Two studies (Ramani & Siegler, 2011; Siegler & Ramani, 2009) considered the role of children's initial math ability level for the impact of linear numerical board games on children's math learning. In both studies, children played a horizontal linear board game with the numbers 1-10, and math outcome measures included counting, number line estimation, magnitude comparison, numeral identification, and addition problems.

Math ability level was considered by examining results based on median splits of pretest math measures. Both studies found that children with initially lower (below the median) math ability showed greater gains from playing the board game than children with initially higher (above the median) math ability levels. This indicates that math games have the potential to increase math outcomes for all children, with benefits for children of lower math abilities. This is important, as games provide a context for children to learn material in an engaging way that is accessible to children of various math ability levels.

Age

Three studies (Guberman & Saxe, 2000; Ramani & Siegler, 2008; Ramani & Siegler, 2011) considered the impact of age on differences in children's math learning. Two studies examined differences for older and younger preschoolers (ages 3-5 years old; Ramani & Siegler, 2008; Ramani & Siegler, 2011). For the same numerical board game, they found that both older and younger preschoolers demonstrated the same learning gains from gameplay, despite starting with initial differences in pretest math outcome scores. This suggests that children are capable of learning from games from an early age, and that age is not a detriment to children's ability to learn from games.

Guberman and Saxe (2000) also examined differences based on age for their Treasure Hunt game which focused on base 10, place value, and arithmetic understanding. Unlike other studies which focus on the age of the child playing the game as a factor, they examined the age of children's peer co-players on children's math development. In examining children's arithmetic strategy use, they found that 3^{rd} graders who played the game with same-age peers (other 3^{rd} graders) used simpler arithmetic strategies, while 3^{rd} graders who played with older peers (4^{th} graders) used more sophisticated arithmetic strategies. This suggests that children may benefit more from playing with children of greater ability levels than playing with same-age peers of the same ability level, highlighting a social aspect of gameplay, in that children's play behaviors and learning are dependent on the abilities, behaviors, and learning of others playing the game.

SES

One study (Ramani & Siegler, 2011) considered differences in learning outcomes by socioeconomic status. In a comparison of children from lower and middle socioeconomic statuses, results indicated that playing the math board game benefitted the children from lower-income backgrounds more than children from middle-income backgrounds, as seen in greater increases in low-income children's number line estimation, magnitude comparison, and addition. This is important, as children from low socioeconomic backgrounds typically begin school with lower math achievement than their higher income peers (Duncan et al., 2007). However, these results indicate that a simple game intervention can benefit math learning for these children.

Gender

One study (Jirout et al., 2018) considered gender as a factor for children's learning. Jirout and colleagues (2018) considered gender as a factor in a spatial scaling physical search game for 5–8-year-olds. This game involved using a map (varying in scaling ratio) to locate a hidden star on a floor-sized checkerboard search space. Math measures included number line estimation. Results indicated that boys and girls performed differently on spatial scaling measures (with results favoring boys), however their number line estimation performance did not differ by gender. This suggests that the impact of gender on spatial scaling ability does not influence its relation with numerical estimation, as both boys and girls demonstrated equivalent estimation abilities.

Summary

These five studies indicate that all children can benefit from playing math games, and in certain cases, these benefits may be greater for some subgroups of children based on their math ability level, socioeconomic background, and age. This is particularly important in the contexts of developing game interventions and the use of games in children's homes and schools. For example, children performing lower in math may benefit from math game play as part of their daily math lessons. In addition, findings about the role of game players of mixed ages could influence how teachers assign classmates to play math games together to allow younger students to further benefit from the games. Similarly, playing games at home with older or younger siblings may also impact children's learning. However, as these results are only representative of five studies, it is clear that more work is needed to further examine and understand how different subgroups of children learn from math gameplay.

What Makes Math Games Effective?

Beyond understanding if math games are effective at promoting children's learning, it is also important to understand why games are effective for promoting children's learning. This section describes findings related to the specific aspects of games and gameplay that make math games effective for math learning. Studies examining what makes games effective for learning fell into three categories: game elements, game instructions/training, and interactions during gameplay. Each of these is described further below.

Game Elements

Eight articles considered game elements effective for children’s math learning. These studies primarily focused on aspects of game design, such as the layout of the game board or the information presented on game materials.

Game Board Design. For numerical board games, four studies examined differences in math learning from play of a linear versus a non-linear (e.g., circular) board game (Elofsson et al., 2016; Ramani & Siegler, 2011; Siegler & Ramani, 2009) or non-linear card game (Whyte & Bull, 2008). Linearity is important to consider as certain foundational math skills, such as number line estimation, build off of a linear representation of numbers. This linear representation is emphasized in the games in multiple ways. For example, the game board itself presents numbers linearly, in order, and evenly spaced. Because of this, during gameplay, children’s moves across the board are directly representative of the magnitudes of numbers—in each of their moves, their counting, and the distance moved on the game board (Siegler & Ramani, 2008). In line with this, all of these studies showed that play of a linear versus non-linear game supports certain aspects of math learning, while other aspects do not differ based on the linearity of the game board.

Every study found support for linear board games enhancing children’s number line estimation abilities more than non-linear games. Studies also showed greater gains from linear gameplay in magnitude comparison (Ramani & Siegler, 2011; Siegler & Ramani, 2009), arithmetic (Elofsson et al, 2016; Ramani & Siegler, 2011; Siegler & Ramani, 2009), and number naming (Whyte & Bull, 2008).

In contrast, other math skills did not differ for linear and non-linear gameplay. These included: numeral identification (Ramani & Siegler, 2011; Siegler & Ramani, 2009), counting

(Whyte & Bull, 2008), number naming (Elofsson et al., 2016), and magnitude comparison (Whyte & Bull, 2008). In addition, for non-linear gameplay, Ramani and Siegler (2011) found that children from middle-income families (but not from lower-income families) also showed gains in arithmetic.

Beyond linearity, Navarrete and colleagues (2018) considered how children learned differently from a linear number game when the numbers were spatially aligned versus misaligned. Children played a 1 to 10 linear life-size board game, where one group of children sat such that the numbers were presented as increasing from left to right (alignment), while the other group of children sat such that the numbers were presented as increasing from right to left (misalignment). They found that children playing with an aligned perspective improved more in number line estimation than children playing with a misaligned perspective. Alignment did not affect counting, numeral identification, or magnitude comparison. These results support the idea that both linear representations and spatial alignment of numerical information are important for children's understanding of numerical magnitudes.

Game Materials and Structure. Three articles examined differences in math learning related to game materials and structure, including labeling of game materials (Loehr & Rittle-Johnson, 2017), design of game materials (Chao et al., 2000), and the structure of multiple games played with the same materials (Scalise et al., 2017). Loehr and Rittle-Johnson (2017) examined the influence of types of labeling in a decimal comparison card game. Third and fourth graders played a decimal magnitude comparison war card game with cards labelled with formal labels (e.g., "two tenths"), informal labels (e.g., "point two"), or no labels. All conditions presented the symbolic numbers along with the corresponding label. Labels were used in these ways as labeling can impact children's symbolic mapping abilities, and therefore influence their learning of decimal magnitudes from the game. Specifically, the authors hypothesized that formal labels would improve children's mapping of decimals to their base ten place value and whole number knowledge in contrast to informal labels. Results indicated that students in the formal label condition outperformed students in the informal label and control conditions on overall gameplay performance, decimal comparison generalization, role of zero comparisons, and place value understanding. This indicates that the information presented on game materials can influence children's learning from math games.

More broadly, Chao and colleagues (2000) considered the impact of the design of game materials on children's math learning across a variety of types of games. Children played sets of number and arithmetic games which either represented numbers structurally with a focus on 5s and 10s or in a varied representation which did not emphasize any structural components of numbers. This choice was based on theories of learning from physical materials, with the idea that the structure of the materials (e.g., 5s and 10s) could allow children to develop a mental image to use during problem-solving, whereas materials with varied structure may promote learning if children abstract common content from the differently structured materials. Results indicated that the type of game materials influenced different areas of math understanding differently. Varied materials led to greater improvements on addition and subtraction accuracy and the understanding of special number relations. Structured materials led to greater improvements on forward number sequences and use of sophisticated addition strategies. Both types of game materials also led to improvements on numerical interference and backwards number sequences.

Finally, Scalise and colleagues (2018) considered how the type of number game played with the same set of cards influenced children's math learning. This study compared learning in two card games: war (which emphasizes numerical magnitude comparison) and memory (which emphasizes numeral recognition). They found differences in learning by game structure for symbolic magnitude comparison, but not for counting, numeral identification, non-symbolic ordinality, or non-symbolic magnitude comparison. This indicates that game structure may influence certain aspects of math learning more than others. In this example, the structure of the War card game specifically allows children to practice comparing numerical magnitudes and to receive feedback from parents on these comparisons, both of which can promote their symbolic magnitude comparison abilities more so than a game, like memory, which does not have this structure.

Summary. Overall, these eight studies show that game design, including game board layout, presentation, and information conveyed through game materials can influence children's learning from math games and make learning more or less effective for children. In addition, these studies indicate that the same types of games played with differently designed materials, and different games played with the same materials, can impact what areas of math children can increase their understanding of through game play.

Game Instructions/Training

Four studies investigated the role of game instructions and training on children's math learning. One study considered parent training, one considered child training, and two studies considered specific gameplay instructions.

Training. Two studies considered the role of providing game training prior to game interventions where parents and children played math games together at home. One study considered the role of training parents (Cheung & McBride, 2017) and one study considered the role of training children (Sonnenschein et al., 2016).

Cheung and McBride (2017) provided training to parents prior to a 4-week, home-based intervention with a numerical board game. The board game was one horizontal row with written numbers 1-30. Training for parents involved a 30-minute training session with an experimenter that explained what, when, and how to teach numeracy during gameplay with their children (Cheung & McBride, 2017). Parents were also given a summary pamphlet to take home with them. While it was expected that children would learn from the games regardless of whether their parents received training, it was expected that children whose parents received training would show greater improvements, as parents who received training would be more likely to provide relevant numeracy guidance based on the examples given in training of what, when and how to teach numeracy skills during the game. Children's rote counting, numeral identification, addition, and math interest were measured pre- and post-intervention. Children whose parents were in the training group showed improvements on rote counting and addition, while children's whose parents were not in the training group did not. Children's math interest and numeral identification improved with or without the parent training.

In contrast, Sonnenschein and colleagues (2016) provided training to children at school prior to a 5-week, home-based intervention. Parents and children played a commercial version of the *Chutes and Ladders* game at home. Parents in all experimental training conditions were trained to count-on while playing the game, and children in training conditions were also trained on how to play the game and had the opportunity to practice taking turns and counting on. Child and parent training took place separately. Parents and children in the control group also completed *Chutes and Ladders* gameplay at home, but did not receive any training.

Math measures included counting, number line estimation, magnitude comparison, and numeral identification. All children showed increases in numeral identification, and children in the child training and sticker chart condition, which combined child training with instructions for parents to give children a sticker to add to their chart whenever they moved up an interval of 10 on the board, showed increases in number line estimation. However, these differences were no longer seen when results were calculated from a subset of the children who were coded as "understanding number line estimation." Children coded as understanding number line estimation included children who either answered more than one third of the questions and put the same answer for no more than one third of the questions. About 44% of children were classified in this group. Results for this group indicate that the reported overall influence on number line estimation abilities may be due to other factors, such as guessing or improperly interacting with the task, rather than a true increase in number line estimation ability.

It is important to note that the child training by itself did not promote gains in math learning. Because the child training plus stickers condition included additional elements of parent-child interaction as well as increased emphasis on intervals of ten, all of these elements overall were what had an impact on children's learning.

Game Instructions. Three studies considered the effectiveness of specific game instructions for numerical board games on children's math learning. All of these studies considered the effect of having game players count on from their space number. Counting on involves counting up from the number of the space the player starts on when they begin their move. For example, if a player was on space 2 and was to move 3 spaces, to count on, they would count "3, 4, 5." Two studies considered this in comparison to instructions to count from 1 (e.g., "1, 2, 3" to move three spaces regardless of what space a player started on), and one study considered this in comparison to standard instructions (which did not include specific instructions for counting aloud during gameplay). Counting on is hypothesized to be beneficial for children's learning because it draws attention to the numbers and their locations on the board, which may facilitate children's understanding of the magnitudes of the numbers in the game.

Sonnenschein and colleagues (2016) compared parent and child game play at home with one of three games—commercial *Chutes and Ladders* with specific instructions to count on, commercial *Chutes and Ladders* with only the standard instructions included with the game, and *Candy Land* (a non-numerical control). In an examination of children's counting, numeral identification, number line estimation, and magnitude comparison, they found that there were no differences in improvement by type of game or instructions. They noted however, that of parents surveyed after the game intervention, only 50% of parents assigned to the count-on condition actually counted on while playing the game and 21% explicitly said they did not count on while playing the game (Sonnenschein et al., 2016). This highlights the importance of considering fidelity for interventions implemented by non-experimenters (e.g., parents or teachers), as the extent to which procedures were implemented may influence the extent of children's learning from the games.

The other two studies (Laski & Siegler, 2014; Skillen et al., 2018) considered kindergartener's gameplay of 0-100 board games at school with an experimenter. Both studies examined the role of instructions to count on versus to count from one on children's learning from the game. They found that following count on instructions led to greater improvements in math than following count from one instructions across a variety of math measures, including counting forward and backward, naming precursor and successor numbers, numeral identification, quantity comparison, a quantity part and composite task, a seriation task, addition and subtraction (Skillen et al., 2018), as well as number line estimation and counting (Laski & Siegler, 2014).

These studies indicate that the instructions provided with games can have a specific influence on the math learning that occurs from games. In particular, there are clear benefits to counting on versus counting from one while playing numerical board games.

Summary. These four studies indirectly emphasize the role of structured interactions surrounding gameplay. The fact that training increases effectiveness indicates the importance of parent involvement in children's learning, as well as the potential malleability of parent-child play behavior. These studies suggest that simple suggestions to parents to increase engagement and math content during gameplay (via talk or sticker charts) has the potential to change parent-child board game play in such a way that benefits children's math learning more than other interactions styles would.

Similarly, the importance of game instructions for children's math learning also relates to the type of structure and guidance children receive while playing the game. The count on instruction is not necessarily intuitive for children, as many children (and adults) would intuitively count from one while playing a numerical board game. This highlights that the structure provided by the parents and experimenters playing the game with children provides further guidance for children's math development, allowing children to engage in more structured numerical practice while playing, and thus learn more from the games.

Interactions During Gameplay

Four studies examined the influence of social interactions during gameplay on children's learning from games. Of these, one study considered children's use of thematic roles during gameplay, and three studies considered different aspects of parent guidance.

Thematic Roles. One study examined children's adoption of thematic roles during gameplay. Guberman and Saxe (2000) examined the role of children's spontaneous use of thematic roles during gameplay on their math learning. Third and fourth graders played a game called Treasure Hunt which focused on base ten understanding, place value, and arithmetic, through the context of collecting, purchasing, and trading doubloons. An examination of gameplay revealed that subgroups of children spontaneously took on thematic roles in the game (e.g., customer, storekeeper) while others did not, and the structure of the roles also provided clarity to the structure of math interactions in the game. Results indicated that children who took on thematic roles during gameplay used more sophisticated problem-solving strategies at posttest than children who did not. This provides evidence that children's interactions during gameplay influence their math engagement during the game and their learning after the game.

Parent Guidance. Three studies examined the importance of parent guidance during gameplay for children's learning. The types of guidance considered included types of parent scaffolding (i.e., responses and instruction to children such as prompting after a child makes an error or modeling a counting strategy; Ramani & Scalise, 2020; Vandermaas-Peeler et al., 2012), parents' use of number words (Ramani & Scalise, 2020), and parent numeracy interactions (e.g., prompts or information related to components of numeracy, such as counting and number recognition; Vandermaas-Peeler & Pittard, 2014).

Ramani and Scalise (2020) examined parent guidance in two types of card games: numerical magnitude comparison (war) or shape and color matching (similar to Uno). Parents/guardians and children played together at home during a six-week intervention. Math measures examined included counting, numeral identification, symbolic magnitude comparison, number line estimation, cardinality, shape knowledge, and shape naming. Results indicated that parents' use of number words during play did not relate to increased math performance for children playing the numerical magnitude game, but did relate to increased counting ability for children playing the shape game. Parent scaffolding during the numerical magnitude game did not relate to children's math performance.

The other two studies examined parent guidance during play of the commercial numeracy game, The Ladybug Game, either over one gameplay session (Vandermaas-Peeler & Pittard, 2014) or over three gameplay sessions during a two-week home intervention (Vandermaas-Peeler et al., 2012). In the single-time point study, children completed the Test of Early Mathematics Ability (TEMA; Ginsburg & Baroody, 2003) and a number concept assessment. Findings indicated that the most common types of parent guidance included counting and number recognition. Parent-child social engagement, defined as references to shared game experiences (not necessarily math-specific) or parent-child connections such as jokes or laughing, also related to children's TEMA scores (Vandermaas-Peeler & Pittard, 2014).

In the intervention study, children also completed the TEMA as a measure of math ability. Parent guidance during gameplay about addition and subtraction related to children's TEMA scores. In addition, the more numeracy questions parents asked children during gameplay related to children's ability to answer complex math questions correctly during the game.

These studies indicate that parent guidance during gameplay can scaffold children's learning in different ways, and emphasizes that different forms of guidance can influence the content and context in which children learn. Parent guidance can include specific types of scaffolding or prompts, as well as use of number words or discussion of math content during gameplay, and different elements of these types of guidance may benefit different elements of children's math learning. In addition, the finding relating social engagement to children's math learning, highlights that non-mathematical aspects of parent-child interactions can also impact how children learn from math games.

Summary. The four articles reviewed demonstrate that both child- and parent-initiated interactions during gameplay can influence children's learning. Children's interactions with peers during gameplay, and the roles they take on unprompted during gameplay, can provide structure that benefits their own math learning. In addition, when children play games with parents, the type of input parents provide can scaffold children's learning, with different types of input bearing different influences on the mathematical concepts children learn from the games.

Summary and Discussion of the Literature

The present review summarizes the evidence of the role of math games in early childhood, and provides support that playing math games can increase children's math knowledge in early childhood. The results presented in the review align with Vygotsky and Piaget's theories, with work showing that children learn from playing games with their parents, peers, and others, and that children's skills and engagement as well as adult guidance and interaction relate to children's learning. They also extend beyond these theories to demonstrate that certain elements of games can be designed to facilitate more meaningful practice and interactions that lead to greater growth in children's math skills, including game board designs, game materials and structure, and the training and instructions provided to adults and children playing the games.

In addition, the findings presented fit within the framework of Playful Learning, in that games can be used to enhance children's understanding of mathematical concepts in an engaging, playful way. In line with the Science of Learning, the games exhibit core features known to promote children's learning, including being active, engaging, meaningful, socially interactive, and providing a context for joyful play and iteration (Zosh et al., 2018). Specifically, the games used in the reviewed studies cover a range of topics across basic and advanced number skills, and contextualize these concepts by putting them into game settings where children can actively practice and develop their math and problem-solving skills. This is relevant for play of games at home as well as in the classroom, fitting with prior research that emphasizes the importance of play in early learning across home and school contexts.

The following sections summarize overall themes of the reviewed studies as well as gaps in the literature and how these will be addressed by the current study.

Overall Themes

Dosage

In examining the role of games for children's math learning, it is important to consider the dosage, or amount of time, children spent playing the games in the studies reviewed. Table 2 presents a summary of the dosage of gameplay for games in the reviewed studies. The majority of studies reviewed were intervention studies, with interventions ranging in length from two weeks to four months. A few studies examined a single session of gameplay, with duration of play lasting 12 to 40 minutes.

Understanding the dosage of play is important for multiple reasons. Firstly, even short durations of gameplay may have profound impacts on young children's math skills. Many of the studies reviewed incorporated gameplay in small increments over their intervention periods. For example, the duration of any single session of gameplay could be as short as 10 minutes (Elofsson et al., 2016), 15-20 minutes (Navarrete et al., 2018; Ramani & Siegler, 2008; Ramani & Siegler, 2011; Scalise et al., 2017; Siegler & Ramani, 2008; Siegler & Ramani, 2009) or 20-25 minutes (Laski & Siegler, 2014; Ramani et al., 2012; Whyte & Bull, 2008). This is important, as it indicates that games can be effective when they are incorporated into play and learning at home or school in small segments of time and do not need to take an abundance of time. In this way, children can benefit from playing games without interfering with instructional time reserved for other areas.

In addition, for gameplay sessions led by a non-experimenter (i.e., parent or teacher) understanding the dosage of gameplay children receive is important for understanding the effects seen in children's math learning. This is especially relevant for games led by non-experimenters as gameplay outside of a controlled research setting may vary more in the amount of time or attention spent on the game, as parents and teachers naturally are not operating under the same strict regulations as experimenters are.

For example, Vandermaas-Peeler and colleagues (2012) reported narrow variability in the amount of time families played the game at home, with differences within about one minute. However, Ramani and Scalise (2020) reported wide variability in the amount of time parents and children played their card games at home, with differences ranging from 13 to 1035 minutes over 6 weeks. Similarly, Sonnenschein and colleagues (2016) reported a wide range of gameplay time, with differences ranging from 130 to 1617 minutes over 5 weeks in one study and from 50 to 2454 minutes over 5 weeks in a second study. Because the amount of gameplay can vary so widely from family to family, understanding the relations of dosage and math learning provides further information about the mechanisms through which gameplay promotes math development. For example, Ramani and Scalise (2020) found that the amount of time children played the game related to their learning gains. When children who play the game more also learn more from the game, this indicates that the activity of playing the game itself promotes math learning. Whereas if the amount of gameplay does not influence the extent of children's math learning, other factors, such as the quality of gameplay or types of interactions during gameplay may have a greater influence on children's math learning. Accordingly, in the current study, dosage was considered as a factor in relation to children's learning from the games. Both the duration of gameplay and the number of days games were played were used as measures of dosage.

Further, it is important to consider the long-term effects of interventions, including how long gains in math ability are maintained, and how the amount of gameplay influences the duration of effects. Two of the reviewed studies included delayed follow-up testing to consider the duration of observed effects. Ramani and Siegler (2008) included a 9-week delayed posttest, and found that improvements in children's math abilities remained. Similarly, Skillen and colleagues (2018) tested children 10 weeks after posttest, and found that effects endured for the linear board game. More work is needed to examine if other types of games and gameplay settings lead to similarly enduring effects, as well as how the dosage of gameplay specifically relates to how long gains are maintained.

Understanding these longer-term effects is important, because they have implications for how games are used to teach concepts. If effects are only concurrent with gameplay, games could be used to provide practice with specific concepts, but would be limited in their use as more than a supplement to other instruction. However, if effects remain after gameplay, then games could also be used as a main form of instruction for the concepts they teach, in addition to providing extra practice with concepts.

Math Outcomes

The studies reviewed included games designed to target both basic and advanced number skills. In considering the effectiveness of the games, it is important to consider how children's math skills were measured. Table 3 presents a summary of the types of math outcome measures included in the studies reviewed. The majority of studies included measures of counting, numeral identification, and magnitude comparison. These measures were typically aligned with children's projected ability level, such that studies of younger children or more basic math concepts used simpler versions of these measures (e.g., including numbers 0 or 1 to 10), and studies of older children and more advanced math concepts used more advanced versions of these measures (e.g., including one-, two-, and three-digit numbers or including decimals). Many studies also included measures of number line estimation and arithmetic, which were similarly implemented with simple and advanced versions of the tasks. Fewer studies included measures of non-symbolic number, place value or base ten understanding, cardinality, or math interest. It is possible that these math skills are less represented in games for early childhood learners, and thus were only included in studies specifically targeting growth in these areas.

Consistent with the distribution of measures used, the majority of improvements in math skills were found in children's counting, numeral identification, magnitude comparison, number line estimation, and arithmetic, with the majority of studies reporting medium to large effect sizes. In addition, many non-significant effects were due to ceiling effects in pretest-posttest study designs. Overall, findings indicate that games can be used to improve a variety of math skills, at both basic and advanced levels of these skills. This is important, as it demonstrates the breadth of potential uses of games at different levels of math instruction and ability levels.

Despite this, more research is needed on the effect of games for math concepts extending beyond the basic and advanced number skills examined here. This could include topics such as geometry, fractions, patterns, foundations of algebra, and measurement or data analysis, as these are all areas of early problem-solving. In line with this, the current study examined games for children's understanding of data analysis and graphing. This is described further in the section addressing gaps in the literature related to mathematical content of games.

Mechanisms

In addition to considering the outcomes studied, it is important to understand the mechanisms which facilitate children's math learning from games. A subset of the studies reviewed targeted this by specifically examining how certain aspects of games and gameplay related to children's math learning. These included aspects such as game board design, game materials and structure, game instructions and training, and parent and child interactions during gameplay. As described above, findings indicated that these factors contribute to children's learning from the games.

Overall, these studies suggest that adapting elements of gameplay to be more aligned with the concepts being taught, either in elements of game presentation or gameplay interactions, is promising for children's math learning. For example, the findings from comparisons of linear and circular board games (i.e., Elofsson et al, 2016; Ramani & Siegler, 2011; Siegler & Ramani, 2009) highlight that children improve in linear number understanding from playing a game that more directly provides them experience with numbers in a linear context. In this way, the game design itself facilitates a type of scaffolding towards the desired math concept. This is important from a game design standpoint, as games should be designed with intentionality about how game elements and structure provide practice for the specific math skills the game intends to improve. In the current study, each game was designed with the intention of providing specific practice with one central element of statistical understanding (e.g., constructing graphs, interpreting graphs).

In addition, studies examining game instructions and training highlight the importance of the interactions during gameplay and the quality of gameplay. Many of the instructional differences or training conditions only provide small manipulations that produce large effects, such as directions to count on versus counting from one (Laski & Siegler, 2014; Skillen et al., 2018; Sonnenschein et al., 2016) or simple suggestions of how to incorporate math into gameplay (Cheung & McBride, 2017; Sonnenschein et al., 2016). This suggests that the ways in which players engage in the game are malleable to simple recommendations, and highlights the importance of providing guidelines for math gameplay, as these can have a profound impact on how children learn from games. Further, understanding how players choose to follow these guidelines is important, as it has implications for how children will learn from the games. The present study examined this by considering implementation fidelity.

Gaps in the Literature

The present review identifies several critical gaps in the literature. Of note are the mathematical content of the games and the role of game type for children's learning. In the following sections, each of these will be discussed further and in the context of the current study.

Mathematical Content

As described above, all of the reviewed studies included mathematical games focused on topics related to either basic or advanced number concepts. While these concepts are important for children's early math learning, they comprise only a subset of the topics that make up mathematics in early childhood. In addition to number and operations, early math also includes algebra, geometry, and measurement and data analysis (Ginsburg et al.; National Council of Teachers of Mathematics, 2000; Sarama & Clements, 2008). As these areas are also important aspects of children's development of math and problem-solving skills, more research is needed on the effect of games for math concepts in these other domains.

The current study focused specifically on the role of games for children's understanding of data analysis and graphs. This area of mathematics has particular importance for children's mathematical and academic development, as data analysis and statistical literacy build on children's early mathematical skills, including both basic and advanced number concepts, and are relevant across academic subject areas. Therefore, developing engaging, effective methods for teaching early data analysis is important, as they have the potential to enhance children's development of statistical understanding and overall math abilities. Further, previous research showing that students continue to struggle with data analysis and graphing in middle school, high school, and college (Lapp & Cyrus, 2000; Leonard & Patterson, 2004; Padilla et al., 1986; Tairab & Al-Naqbi, 2004), highlights the need for additional practice and support with these skills in earlier grades. Specifically, participating in active, meaningful graphing activities, such as games, in early grades has the potential to help children develop a stronger foundational statistical understanding, with implications for their later learning and use of data analysis and graphing skills throughout the lifespan.

For young children, data analysis is an application of their foundational math skills, including counting, numerical magnitude comparison, and arithmetic (National Governors Association, 2010). For example, when children see a graph of their class's favorite ice cream flavors, they may use their counting skills to determine how many students chose each flavor of ice cream. To know which ice cream flavor was selected the most, they may count to know how many of each flavor was chosen, and then use their magnitude comparison skills to compare the numerical values of each flavor category (e.g., 5 classmates picked strawberry ice cream and 7 classmates picked vanilla ice cream, and 7 is more than 5, so vanilla ice cream was the most popular choice). Further, children may use their arithmetic skills to understand how many more or less students chose a specific flavor (e.g., 7 minus 5 is 2, so 2 more students chose vanilla ice cream than strawberry ice cream), as well as how many total students voted (7 plus 5 is 12) or chose a particular subset of flavors. In this way, understanding and interpreting data contextualizes numbers and mathematical relations and builds on skills children have learned more abstractly. Specifically, when engaging in data analysis children learn to consider numbers in context and apply their understanding of mathematical relations to interpret and make inferences about the information presented in that context (English, 2013; Franklin & Mewborn, 2008; Russell, 2006; Sharma et al., 2010).

In addition, statistical literacy is important across academic subject areas, including math, science, reading, social studies, as well as real-world experiences (Basile, 1999; Padilla et al., 1986; Niezgoda & Moyer-Packenham, 2005). For example, children may encounter or be asked to create graphs and charts in all academic subject areas. For science, children may make graphs of the type of weather each day of the month or the number of days it takes plants to grow. For reading, children may make graphs related to the number of uses of specific letters or phrases in a particular passage or context. For social studies, children may make graphs of the use of colors in state or world flags. And for real-world experiences, students may make graphs of contexts encountered on field trips, such as the number of each type of animal they saw on a trip to the zoo. As graphing and being able to interpret the information in graphs is relevant across all of these areas of students' learning, it is important for students to have a strong foundation in their skills to create and interpret graphs.

Basic statistical literacy is also important for understanding and making inferences from information received from external sources. Engaging in data analysis provides students with an opportunity to practice interpreting numerical information and to further develop their critical thinking skills, which are necessary for engagement in real-world contexts throughout the lifespan (Glazer, 2011; Gultepe, 2016; Larson & Whitin, 2010; Roth & McGinn, 1997; Sharma et al., 2010). For all of these reasons, developing engaging, effective methods for teaching early data analysis is important, as they have the potential to enhance children's development of statistical understanding, overall math abilities, and higher order thinking skills.

The games used in the current study were designed to promote children's early understanding of graphs by providing engaging, direct practice with foundational concepts related to graphs—constructing graphs and interpreting information presented in graphs. Aligned with the Science of Learning and Playful Learning frameworks, the games used in the current study were designed to provide children with active, engaging, and meaningful practice with graphing, in a context of play that is socially interactive, joyful, and iterative. The graphs included in the games put numbers into familiar contexts that are relevant across subject areas and life experiences, including graphs about favorites (e.g., foods, books, sports), family size, weather, and going to the zoo, among other topics. The specific features of the games designed to promote learning of these concepts are delineated in Chapter 3.

Game Type

It is also important to consider how the type of game played impacts children's learning. While many of the reviewed studies were experimental and included some type of control game or activity, these were either not math-related or included math content presented in a non-game context. To further understand how games promote children's math learning, studies that compare multiple games designed to teach the same math content across game type(s) or settings are needed. For example, a study could examine if playing a card game or a board game covering the same math content produces greater gains in children's math skills. This is important, as the structure of the game could influence children's math learning, and it is possible that certain topics align more with a certain type of game design or format based on the types of numerical representations each format provides. In the present study, a graphing board game and graphing card game were compared, and it was expected that the structure of the board game would promote children's ability to construct graphs and that the structure of the card game would promote children's ability to interpret graphs. Both of these skills are important for children's early statistical understanding, and it is important to understand how each type of game may promote these skills differently.

The graphing board game was designed such that children were presented with a graphing context and would use their moves throughout the game to construct a graph based on the data presented in the graphing context. On each turn, children had to consider the number of items that were supposed to be represented in each category and consider this in relation to what was currently represented on their graph game board. Accordingly, the game provides direct practice with using given data to construct a graph. In addition, the structure of the game board also highlights elements important for constructing graphs, including starting markings for each category at zero on the y-axis and the necessity to represent each category individually on the graph. These elements in concert with the practice filling in the graph based on the provided context are expected to specifically promote children's abilities to make graphs.

In contrast to the graphing board game, in the graphing card game, children were not given the graphing context, but rather had to use the information presented in the graph to interpret the magnitudes represented for each category on the graph. Similar to the card games studies described above (Chao et al., 2000; Ramani & Scalise, 2020; Scalise et al., 2017), the information on the cards represented numerical magnitudes in multiple ways on the cards. In the current card game, children could see the magnitude of the categories on the graph in three ways, (1) by considering the amount of space each bar or set of objects occupies for each category, (2) by counting the number of discrete objects or grid spaces there are for each category, and (3) by reading the corresponding numeral for each category on the y-axis of the graph. These representations, along with parent feedback provided for comparisons, are expected to promote children's ability to interpret information and compare the magnitudes depicted in graphs.

With these games, the current study fills a gap in the literature both by comparing children's learning from two types of games, as well as by comparing learning from math games targeting different, central aspects of the math content of the game (e.g., constructing graphs and interpreting graphs). Therefore, results provide evidence on the role of game type and content for children's statistical understanding and broader math abilities.

Implementation Fidelity

Finally, while the majority of studies reviewed included some type of exploration of what makes games effective, future studies should further examine these factors. Of particular interest are the elements of games that depend most on game players, such as game instructions, frequency of gameplay, and interactions during gameplay. While some of the reviewed studies included measures of and information regarding implementation fidelity, other studies did not provide information on fidelity to gameplay instructions, expected duration of gameplay, or adherence to training directives. This is especially important in cases where games are played in more naturalistic settings, such as children's homes, or with different players (e.g., parents, teachers, peers), as both interaction styles and fidelity to instructions and training could vary widely depending on the context of gameplay.

In the present study, children played games at home with their parents. Further understanding how children and parents follow game instructions, adhere to the game training protocol, and interact during gameplay will provide clearer evidence of how the games promote children's math learning. In the current study, this was examined through coding of gameplay sessions for implementation fidelity, as well as through parent self-reports of their gameplay behaviors and interactions.

Chapter 3: Methods

Participants

Data were collected from 148 children ages 5- to 6-years-old (M_{age} = 71.14 months, range = 59 to 83 months, 50% female) and their parent/legal guardian. The age range was selected based on the Common Core Standards for kindergarten, first, and second grades related to representing and interpreting data (National Governors Association, 2010).

An additional 31 families enrolled in the study but did not complete a pretest, and therefore were not included in the study. An additional 30 children completed a pretest but were excluded from final analyses for not completing a posttest. Of these, 6 participants actively withdrew from the study, and 24 participants passively withdrew from the study (i.e., never replied to emails about scheduling a posttest [n = 15], replied but never scheduled a posttest [n = 2], or scheduled a posttest but had to cancel and were not able to reschedule [n = 7]).

Participants were recruited from social media posts, email listserv posts (e.g., cogdevsoc), and online data collection websites (e.g., ChildrenHelpingScience.com), as well information shared by schools, children's museums, and libraries. In order to be able to mail study materials to participants, participation was limited to participants living in the United States and Canada. Figure 1 shows a summary of participants' general geographic locations. Parents/guardians provided informed consent and children provided verbal assent prior to participation in the study. At the time of consent, parents completed a demographic survey (items listed in Appendix A). Table 4 shows descriptive statistics for these demographic survey variables.

Design

The study used an experimental intervention design with three conditions and pretest and posttest assessments of children's mathematical knowledge (see Table 5). Children were randomly assigned to one of three game conditions—the graphing card game condition, the graphing board game condition, and the literacy board game (active control) condition—with assignment stratified by children's age and gender to maintain similar numbers of girls and boys and 5- and 6-year-olds in each group.

Procedure

Data were collected between March 2021 and September 2021. Families completed a pretest, 4-week intervention, and posttest. All pretest and posttest sessions were conducted online via Zoom. At each test session, children completed measures of their statistical understanding and general math ability. After their child completed the posttest session, parents completed an additional parent survey including questions about game implementation fidelity, enjoyment, and perception of children's familiarity and change in understanding of the game concepts.

During the intervention period, parents and children were asked to play a brief (~15 minute) game together in their home at least three times per week for a period of four weeks. All game materials were mailed to families. Families were provided with two versions of the game they were assigned and were asked to play each version for a two-week period. Instructions for playing the game were provided in two ways. First, the game materials sent to families included written instruction sheets. Second, parents were sent a link to a video of the experimenter describing how to play the game and demonstrating how to use the materials.

Families were also asked to record a video of their first session of gameplay during the third week of the intervention (e.g., the first time playing the second game) and instructed to upload it to their personal online Box folder (see Figure 2). Families were also provided with a paper gameplay log as well as a link and QR code to access an online version of the log to record the days and times they played the game with their child (see Figure 3). Parents were also emailed weekly reminders during the intervention period to remind them to play the game with their child and to fill out their paper or online log each time they played. Families were also provided with a paper and online copy of a weekly play checklist (see Figure 4) that summarized what they should do during each week of the study.

Experimental Conditions

Participants were randomly assigned to one of three experimental conditions. (1) Graphing Card Game, (2) Graphing Board Game, and (3) Literacy Board Game (Active Control). The graphing card game was focused on interpreting the information presented in graphs, including identifying and comparing amounts of items in the categories represented on the graphs, and the graphing board game was focused on constructing graphs from data. Both games focused on these topics specifically for picture graphs and bar graphs, as children's early experiences with data build on their experiences with classification of objects, and both picture graphs and bar graphs are a way to represent categories of data. In the current study, picture graph games were played before bar graph games, because bar graphs provide a more abstract representation of the content in picture graphs, and therefore starting with picture graphs allows children to progress from more concrete to more abstract representations of data (Friel et al., 2001, as cited in Van de Walle et al., 2018). Table 6 provides a summary of the materials families in each condition used each week of the intervention.

Graphing Card Game

For the graphing card games (called *Dare to Compare: Pictures!* and *Dare to Compare: Colors!*), parents and children were given a deck of 25 cards with each card depicting a graph or chart (see Figure 5). For the first two weeks of the intervention period, the game included cards that depicted picture graphs, and for the second two weeks, the game included cards that depicted bar graphs. In both games, each graph represented quantities of five categories of information, and each category was represented with a color (e.g., red, yellow, green, blue, or purple). A set of corresponding color tokens was included in the game materials so that parents and children could each select a color to use each time they played the game. In order to ensure the game could be played repeatedly without redundancy, parents and children were asked to choose different colors each time they played.

Gameplay was similar to the card game "War," except that one stack of cards was shared by both players instead of each player having their own stack. To play the game, parents and children were instructed to shuffle the deck of cards and place the deck face down between them. Players would then each choose a color token that would be used throughout the game. On each turn, one player would flip over one card from the top of the deck, put it in the middle, and read the title of the graph out loud. Then, each player would say the number represented on the graph for their color and the category it represented (e.g., for green, "There are 6 chocolate cupcakes at the bakery."). Parents were instructed to prompt their child to count the pictures/color squares if their child was not sure how many their color had. Next, parents would ask their child which category had more (e.g., For green and blue, "Were there more chocolate or carrot cake cupcakes at the bakery?") The player whose color had the larger amount would win the card (and put it in their own separate pile). If both players' colors had the same amount, they would do a "War" with the cards, flipping over an additional card and comparing the amounts on that card to determine who would win both cards. Players would continue until the entire deck of cards had been used. To end the game, each player would count the number of cards in their pile, and the player with the most cards would win the game. The decks of cards were balanced such that each color would have an equal chance of winning in a two-player game.

The game is expected to enhance children's abilities to interpret information from graphs by providing children with direct practice identifying the number of objects in a category represented by the bars or pictures on graphs and making magnitude comparisons of these across multiple categories depicted in the graph. These skills are essential for interpreting the information shown in graphs. Specific features of the card games that are expected to promote children's abilities to interpret graphs include the representations of magnitude on the cards, increased exposure to graphs of familiar subjects and contexts, and parent feedback (Table 7 provides an overview of these features).

Graphing Board Game

The graphing board games (called *Top the Chart!* and *Raise the Bar!*) involved parents and children rolling dice and collecting tiles to make a graph. Both players each had their own small identical game board. The game boards showed a description of the graph context (e.g., "A kindergarten class went to the zoo and counted the animals they saw. They saw 10 giraffes, 3 dolphins, 6 lions, 2 elephants, and 7 zebras") as well as an empty graph template (see Figure 6). Tiles were sized to fit into the squares on the graph template and depicted the categories represented on the graph (e.g., giraffes, dolphins, lions, elephants, and zebras). Parallel to the graphing card game condition, for the first two weeks of the intervention period, the game board was for a picture graph, and for the second two weeks, the game board was for a bar graph. To be consistent with the orientation of graphs shown in the graphing card game, the game board for the picture graph was displayed vertically with category labels on the x-axis, and the game board for the bar graph was displayed horizontally with category labels on the y-axis.

To play the game, parents and children were instructed to place the picture/color tiles between each of their game boards and use both the picture/color and number dice to play. Before starting, players would read the description of the graph context at the top of the board out loud. On their turn, players would roll two dice to determine the actions to complete during that turn. One dice indicated the number of pieces to add to their game board (values included 1, 2, and 3). The other dice indicated the type of pieces to add to their game board (e.g., the items corresponding to each of the categories represented by the graph). For the picture graphs game, this dice included pictures of a giraffe, dolphin, lion, elephant, and zebra, as well as a “pick any animal” side. For the bar graphs game, this dice included color dots for green, yellow, red, purple, and blue, as well as a “pick any color” side. When adding tiles to the graph, each player would describe what they were adding (e.g., “I added 2 giraffe tiles, which shows that they saw 2 giraffes at the zoo.”). If the total number of tiles would exceed the number listed in the graph description, a player would add the number needed and discard any remaining tiles (i.e., put them back in the central pile of tiles). If a player already had the number needed for a certain category and they rolled that category (e.g., rolling an elephant when they already had the necessary two elephants), they would skip their turn.

Parents were instructed to prompt their child to count the tiles on the graph if their child was not sure how many tiles they had for a certain category. Players would continue taking turns until one player successfully completed their graph. To end the game and determine if the graph was completed correctly, each player would count the number of tiles that they had in each category and compare the number given in the graph description (e.g., “My graph shows 10 giraffes, and they saw 10 giraffes at the zoo.”). The first player to complete their graph correctly would win the game.

The game is expected to enhance children’s abilities to construct graphs by providing children with direct practice filling in a graph template based on a description of collected data. These skills are important for children’s understanding of data and representing data in different styles of graphs. Specific features of the board games that are expected to promote children’s abilities to interpret graphs include the graphing context (i.e., written description of data), direct practice constructing a graph from data, and highlighting of different features of graphs (Table 7 provides an overview of these features).

Literacy Board Game

The literacy board games (called *Match It: Alphabet Matching!* and *Match It: Rhyme Matching!*) were structured similarly to the graphing board games, in that parents and children each had their own game board and were playing to fill in their boards. To complement the other conditions, for the first two weeks of the intervention period, the game board was for alphabet matching, and for the second two weeks, the game board was for rhyming word matching (see Figure 7).

Gameplay was similar to a “bingo” style game. To play the game, parents and children were instructed to place the picture/rhyme cards between each of their game boards. On their turn, players would roll a number dice (values included, 1, 2, and 3) to determine how many cards to draw. Players would then draw the number of cards and say what was on their card. For the alphabet matching game, players would label the picture on their card (e.g., “Watermelon”) and the letter it started with (e.g., “W”). Then, players would add the card to the matching space on their game board (e.g., the “Watermelon” card would be added to the “W” space). For the rhyme matching game, players would read the word on their card (e.g., “Net”) out loud. Then, players would add the card to the matching space on their game boards (e.g., the “Net” card would match the “Vet” space). If a player already had a card covering the matching space for a certain letter/rhyme, they would discard any extra letter/rhyme cards (i.e., add them to a separate discard pile). If the stack of letter/rhyme cards ran out before the game ended, parents were instructed to shuffle the discard pile and continue playing with those cards. Players would continue taking turns rolling the dice and adding cards to their boards until one player covered all of the spaces on their board. The first player to cover all of the spaces on their board would win the game.

These games were intended to serve as an active control in comparison to the graphing board and card game conditions. In playing, children had a parallel experience of parent-child game play over the four-week intervention, however, the play was not focused on any mathematical or statistical content.

Materials and Measures

At pretest and posttest, children completed measures of Statistical Understanding, Arithmetic, and Magnitude Comparison. The same measures were used at pretest and at posttest. The order of measures (i.e., 1. Statistical Understanding, 2. Arithmetic, 3. Magnitude Comparison) was the same for all participants. All pretest and posttest sessions were conducted online via Zoom. For all measures, all questions were presented via PowerPoint slides via the share screen function on Zoom. Sample task scripts are included in Appendix B. For posttests, 52% of the sessions were conducted by an experimenter blind to the participant’s condition and the hypotheses of the study.

Statistical Understanding

Children completed a measure of statistical understanding comprised of 18 items. These items were developed for the current study based on teacher-created activities and materials related to graphing instruction for preschool through third grade, PARCC sample items for third graders, age-appropriate questions and curricula on instructional websites (e.g., Khan Academy), and online graphing activities for children.

The questions focused on two areas of children's understanding—interpreting graphs (9 items) and constructing graphs (9 items). For each area, questions covered the content for both picture graphs and bar graphs, as these were the types of graphs represented in the intervention games. For interpretation questions, children were shown a graph and asked to answer questions about the information presented in the graph, including identifying which category had the most, identifying and comparing magnitudes of specific categories, and counting or adding total amounts. For questions about constructing graphs, children were given information about a graphing context and shown three graphs (with the colors blue, purple, and green). They were asked to identify which of the presented graphs was correct for the given context by saying which color graph was their answer (see Figure 8).

For each question, the experimenter read the question aloud and recorded the child's response. Responses were scored as correct or incorrect, and the number of correct responses both overall and for each subsection (e.g., interpreting or constructing graphs) were used as outcome variables.

Math Ability

Two measures of children's broader math abilities were used, a measure of magnitude comparison and a measure of arithmetic. These content areas were selected because graphing abilities build on children's understanding of these mathematical concepts. For example, to interpret information presented in a graph, children need to be able to identify and compare the magnitudes represented for each category. Similarly, arithmetic is involved in understanding the magnitudes of categories represented on graphs, as interpreting graphs includes adding total amounts across categories as well as adding and subtracting to determine how many more or fewer items one category may have in comparison to another.

Magnitude Comparison. For magnitude comparison, children were shown pairs (20 items) or sets of three numbers (16 items) on a PowerPoint slide and asked to choose which number was more (e.g., "Which is more, 5 or 6?"; see Figure 9). Sets of numbers (e.g., 10, 15, 8) were used in addition to pairs of numbers, as interpreting graphs can involve comparing the values of more than two numbers or categories. The task included comparisons of the numbers 1 to 9 as well as comparisons of larger numbers, with values ranging from 10 to 81 (adapted from Ramani et al., 2019). For number pairs, ratios ranged from 0.20 (e.g., 1 and 5) to 0.93 (e.g., 82 and 88). Pairs were balanced such that the larger number was presented on the left in half of the pairs. For sets of three numbers, sets were balanced such that the largest number was presented in the left, center, and right positions each one-third of the time. For each question, the experimenter read the question aloud and recorded the child's response. Children's responses for each question were scored as correct or incorrect, and the total number of correct responses was used as the outcome variable.

Arithmetic. Children's arithmetic ability was measured with a task including addition (8 items), subtraction (8 items), and word problems (6 items). Children were shown arithmetic problems one at a time and asked to provide an answer (see Figure 9). Children were asked to complete the problems mentally without writing anything down. Addition problems included problems with two single-digit addends (e.g., 3 + 9) as well as problems with one single-digit addend and one double-digit addend (e.g., 11 + 5). Subtraction problems included problems with a single-digit minuend and a single-digit subtrahend (e.g., 8 – 4), as well as problems with a double-digit minuend and single-digit subtrahend (e.g., 15 – 6). For both addition and subtraction problems, problems were presented in a typical format (e.g., 3 + 9). Word problems included three addition problems and three subtraction problems. For each, two problems had a result unknown structure (e.g., 5 + 6 = __ and 8 – 2 = __) and one problem had a change unknown structure (e.g., 4 + __ = 11 and 13 – __ = 5). The specific problems used were adapted from other arithmetic measures for children of similar ages (Elofsson et al., 2016; Ramani et al., 2019) as well as from problems used in standardized measures such as the Test of Early Mathematics Ability (TEMA-3; Ginsburg & Baroody, 2003) and Woodcock Johnson IV Calculation subtest (Schrank et al., 2014). For each question, the experimenter read the question aloud and recorded the child's response. For each problem, children's responses were scored as correct or incorrect. The total number of problems correct was used as the outcome variable.

Number, Math, and Stats Talk

Families were asked to record the first session of gameplay during the third week of the intervention (e.g., the first time playing the second game). The first fifteen minutes of each recording were transcribed. Fifteen minutes was selected as the length for the transcripts, as instructions to families asked them to play the game for at least fifteen minutes each time they played. Initial transcriptions were generated by a transcription service (e.g., Otter.ai, Speechpad), and all transcripts were verified and finalized in CLAN software. Eight families used occasional words or phrases in languages other than English (e.g., French, Spanish, Portuguese). These were translated into English by native speakers of the language during transcription.

Parent and child use of number, math, and stats talk were extracted from the transcripts. One measure was the number of number words 0 to 100 that parents and children each used. These were considered in total, as well as broken down into small (e.g., 0 to 10), medium (e.g., 11 to 20), and large (21 to 100) number words. Consistent with previous studies examining parent-child number talk (Levine et al., 2010), non-numerical uses of the word *one* (e.g., *this one, that one*, *another one*) were not included in the final number of number words used.

Other measures included the number of mathematical words (e.g., words related to math and mathematical operations) and statistical words (e.g., words related to statistics and graphs) parents and children each used. Specifically, the following math words were identified and extracted from transcripts: *how many*, *most*, *least*, *more*, *less*, *plus*, *minus*, *equal*, *same number*, *how much*, *fewer*, *same amount*, *count*; and the following statistical words were identified and extracted from the transcripts: *data*, *graph*, *axis*, *number line*, *category*, *categories*, *chart*, *bar*, *statistics*, *stats*, *variable*, *measure*, *scale*, *label*, *plot*, *row*, *column*, *line*.

Implementation Fidelity and Dosage

To capture variation in implementation fidelity in the home-based setting, multiple measures to assess each family's dosage of gameplay and fidelity to intervention game instructions were included. These measures of the amount and content of gameplay were collected to have a deeper understanding of the mechanisms by which the games promote learning of early math concepts.

Dosage of gameplay was calculated from the gameplay logs families filled out. Measures included the number of minutes played as well as the number of days the game was played. Measures of implementation fidelity included parent self-report items administered at the end of the intervention period (see Table 8).

In addition, recordings of gameplay for the graphing card game and graphing board game conditions[1] were coded for fidelity to game instructions. The first fifteen minutes of each recording were coded for parent and child behaviors related to adherence to game instructions. Table 9 delineates the behaviors and game components rated for each game type. Coding was completed by two coders. The first coder coded all of the videos, and the second coder coded 20% of the videos. Percent agreement was used as a measure of reliability. For the Board Games videos, percent agreement was 100% for the first item, 88% for the second item, and 100% for the third item. For the Card Games videos, percent agreement was 100% for the first item, 100% for the second item, and 86% for the third item. For any disagreements, the first coder's coding was used.

Parent Posttest Survey

In addition to questions related to gameplay implementation fidelity, the survey parents completed after their child had completed the posttest included items for parents to provide ratings of their and their child's enjoyment of the games, and indicate their perception of children's familiarity with the game concepts (e.g., picture graphs, bar graphs) prior to playing the games as well as their perception of any changes in their child's understanding of these concepts after playing the games. The same items were used for all conditions. Items and descriptive statistics for each condition are provided in Chapter 4.

[1] Recordings from the literacy game condition were not coded, as the intervention did not target skills from the literacy games.

Child Engagement and Effort in Pretest and Posttest Sessions

To examine variability in children's participation in pretest and posttest sessions, video recordings of each session were rated for children's engagement and effort throughout the session. All ratings were made by experimenters who were blind to the participant's condition and the hypotheses of the study. Table 10 defines the ratings used (adapted from Jaeggi et al., in prep).

Data Analysis

Preliminary Analyses

Preliminary analyses were conducted to examine if there were any differences across conditions in children's statistical understanding at pretest, to determine if children's pretest ability should be included as a covariate in subsequent analyses. However, because children were randomly assigned to conditions, pretest differences were not expected. In addition, preliminary analyses were conducted to examine if there were any differences by condition in annual household income and dosage of gameplay, to determine if these variables should be included as covariates in subsequent analyses.

Missing Data

As described above, children who did not complete any posttest measures were not included in the study. There was no missing data for pretest and posttest measures, with the exception of one child who did not complete the magnitude comparison task at posttest. For Aim 1a, this instance of missing data was handled with maximum likelihood estimation. All other instances of missing data (e.g., missing gameplay log, play video, or parent survey data) were handled with pairwise deletion.

Primary Analyses

Aim 1a. The first aim was to examine if playing graphing games led to improvements in children's ability to construct and interpret graphs. The initial planned analysis for this Aim was a 2 x 3 repeated measures MANOVA with univariate analyses for any significant overall differences. However, as the statistical understanding, arithmetic, and magnitude comparison variables were not normally distributed at pretest or posttest, and because the aim was focused on considering each variable separately, repeated measures MANOVA was not an appropriate analysis to address Aim 1a.

Structural equation modeling (SEM) was used to examine Aim 1a instead. Analyses were conducted using Mplus Version 8.7. SEM involves two modeling phases—a measurement model which shows how measured variables are indicators of latent variables, and a structural model which shows relations among latent variables. In the current study, multigroup second-order latent growth models were used to examine changes in children's statistical understanding, arithmetic, and magnitude comparison from pretest to posttest. Separate models were used for each measure (i.e., statistical understanding, arithmetic, magnitude comparison). MLR estimation was used, as it is robust to non-normality.

Prior to fitting the growth models, confirmatory factor analysis models were fit to examine the fit of the measurement models to the data. Separate models were used for each measure. Figure 10 shows the confirmatory factor analysis models for statistical understanding, arithmetic, and magnitude comparison. Measured variables are shown in rectangles and latent variables are shown in circles. Factors included ability at pretest (time 1) and posttest (time 2). For statistical understanding, these were indicated by interpreting graphs and constructing graphs variables. For arithmetic, these were indicated by addition, subtraction, and word problems variables. For magnitude comparison, these were indicated by single-digit pairs, double-digit pairs, single-digit sets, and double-digit sets variables. For each factor, corresponding factor loadings were constrained to be equal, to assume invariance across time points as the same measures were used at each time point. In addition, corresponding residuals (e.g., pretest interpreting graphs and posttest interpreting graphs) were set to covary, as the same participants completed measures at each time point.

Table 11 shows a summary of fit indices for the models. The indices used to evaluate data-model fit included the root mean squared error of approximation (RMSEA; parsimonious index) and the standardized root mean squared residual (SRMR; absolute index). Guidelines suggest that SRMR values less than or equal to 0.08 and RMSEA values less than or equal to 0.06 are indicative of adequate data-model fit (Hu & Bentler, 1999). Model fit was good for the statistical understanding model, adequate for the arithmetic model, and inadequate for the magnitude comparison model. Because the model for magnitude comparison had poor data-model fit, magnitude comparison was not examined in the growth model phase.

Figure 11 shows the growth models conducted for statistical understanding and arithmetic. Second-order factors included intercept and growth factors. First-order factors included ability at pretest (time 1) and posttest (time 2). Overall, these models allow for variability in each group to differ, and they allow for examining differences across conditions in any parameter of interest in the model. In the current models, the parameter of interest was the mean growth over time (growth factor). To examine differences by condition in this parameter, each difference (e.g., $M_{Growth:BoardGames} - M_{Growth:CardGames}$) was coded as an additional parameter and tested in the model.

Aim 1b. Aim 1b was to examine if playing a board game versus a card game led to differences in improvements in children's statistical understanding abilities. To examine this question, t-tests were used to compare pretest-posttest gains in interpreting graphs and constructing graphs scores between the board games and card games conditions.

Aim 2. The second aim was to examine if the numerical, mathematical, and statistical talk parents and children used during play related to gains in children's statistical understanding and math abilities. To examine this question, one-way ANOVAs were used as a preliminary analysis to examine differences in talk across conditions. Correlations by condition of parent and child statistical, mathematical, and numerical talk with children's gain scores (from pretest to posttest) on statistical understanding and math ability measures were used to examine the relations of parent input with children's learning.

Additional Analyses. Additional exploratory analyses were conducted to further examine children's learning from the games. These included analyses examining dosage of gameplay, children's engagement and effort during the pretest and posttest sessions, and parent survey measures, as well as comparisons of subgroups of participants based on condition, timeframe of completing the posttest, and initial statistical understanding ability at pretest.

Chapter 4: Results

Descriptive Statistics

Pretest and Posttest Measures

Table 12 shows descriptive statistics for pretest and posttest measures of statistical understanding, arithmetic, and magnitude comparison, by condition.

Time Between Test Sessions

There was variability in the length of time between children's pretest and posttest. Overall, the time between pretest and posttest sessions ranged from 24 to 86 days (M = 40.78, SD = 12.18). Table 13 shows descriptive statistics for length of time between sessions by condition, including both the number of days between the pretest and posttest sessions and the number of days between the start of Week 4 (the final week) of the intervention and the posttest. One-way ANOVAs indicated that there were no differences by condition in days from pretest to posttest ($F(2,145)=.712$, $p=.492$) or days from the start of Week 4 to posttest ($F(2,145)=1.264$, $p=.286$).

Parent-Child Game Play Videos

In total, 104 families (70%) submitted useable videos of their game play. Two additional families submitted videos that were not useable (one did not include any audio, and one was less than one minute in length and only included a child speaker). Useable videos ranged in length from 1.57 minutes to 46.32 minutes (M = 17.84, SD = 7.98). For all analyses, only the first 15 minutes of each video were used, as instructions to families asked them to play the game for at least 15 minutes each time they played.

Of the videos submitted, 88% (n = 91) included the child's mother as the participating parent, and 12% (n = 13) included the child's father as the participating parent. Overall, 83% of videos (n = 86) included two players (e.g., the participating parent and the participating child), 16% (n = 17) included three players (e.g., the participating parent, the participating child, and one sibling; or the participating parent, another parent, and the participating child), and less than 1% (n = 1) included 5 players (e.g., the participating parent, another parent, the participating child, and two siblings). For all primary analyses, the participating parent's and participating child's talk were used. Descriptive statistics for these speakers and a composite of all other speakers (e.g., non-participating parents, siblings) are reported below in Table 14.

Number, Math, and Stats Talk

Parent and child use of number, math, and stats talk were extracted from the transcripts. In addition to the number of number, math, and stats words used, proportions were also calculated for each measure of talk (e.g., number of math words divided by total number of words used). Descriptive statistics for parent and child use of talk by condition are shown in Table 14. For number talk (i.e., use of number words 0 to 100), talk was further broken down by number size (e.g., small, medium, large; see Figure 12). Because the vast majority of number talk was comprised of use of small number words (numbers 0 to 10), these categories were not further analyzed separately.

Dosage of Gameplay

In total, 142 families (96%) submitted logs of their gameplay, including five families who reported that they did not play at all. Six families (4%) did not submit a log, stating that they filled out their paper log but lost it or otherwise couldn't return it (n = 4), played the games but didn't keep a log (n = 1), or did not receive a log (n = 1). Overall, total number of dates played ranged from 0 to 16 (M = 9.28, SD = 3.87), and total number of minutes played ranged from 0 to 710 (M = 172.29, SD = 102.53). Table 15 shows dosage of gameplay by condition.

Child Engagement and Effort in Pretest and Posttest Sessions

There was variability in children's engagement and effort during the pretest and posttest sessions (see Table ***16***). A one-way ANOVA indicated that there was a significant difference between conditions in posttest engagement (F(2,145)=4.292, p=.015), with post hoc tests indicating that engagement was significantly lower for children in the card games condition (M=4.08) than the board games (M=4.47) or literacy games (M=4.60) conditions. There were no significant differences between conditions in pretest engagement (F(2,145)=1.123, p=.328), pretest effort (F(2,145)=2.675, p=.072), or posttest effort (F(2,145)=2.320, p=.102).

Parent Posttest Survey Measures

In total, 141 parents (95%) completed the parent survey after their child completed the posttest. There was variability in parents' responses. Table 17 shows descriptive statistics for ratings of enjoyment and perception of children's familiarity with the game concepts, and Table 18 shows descriptive statistics for perception of children's change in understanding of the game concepts.

Preliminary Analyses

Preliminary analyses were conducted to examine if there were any differences across conditions in children's statistical understanding at pretest. One-way ANOVAs indicated that there were no differences by condition at pretest in children's overall statistical understanding scores ($F(2,145)=.361$, $p=.698$), interpreting graphs scores ($F(2,145)=.328$, $p=.721$), or constructing graphs scores ($F(2,145)=.388$, $p=.679$). Therefore, pretest ability was not included as a covariate in subsequent analyses.

In addition, one-way ANOVAs were used to examine if there were differences by condition in annual household income and dosage of gameplay. Results indicated there were no differences by condition in income ($F(2,143)=.891$, $p=.412$), total dates played ($F(2,139)=.696$, $p=.500$), or total minutes played ($F(2,139)=.363$, $p=.696$). Therefore, annual household income and dosage of gameplay were not included as covariates in subsequent analyses.

Finally, prior to conducting the analyses for Aim 1a, the Mahalanobis distance was calculated for each participant from their pretest scores on statistical understanding, arithmetic, and magnitude comparison to determine if there were any multivariate outliers. Based on the distances calculated, one participant was determined to be an outlier (Distance=31.31, $p<.001$) and was not included in analyses for Aim 1a.

Primary Analyses

Aim 1a

The first aim was to examine if playing graphing games led to improvements in children's statistical understanding and math abilities. Structural equation modeling was used to examine this aim. Specifically, multigroup second-order latent growth models were used to examine differences in statistical understanding and arithmetic between each of the study conditions. As described in Chapter 3, a growth model was not conducted for magnitude comparison, because the measurement model had poor data-model fit. Models were conducted separately for each measure (i.e., statistical understanding, arithmetic). For each model, the parameters of interest were the mean and variance of the growth and intercept factors.

The fit indices used to evaluate data-model fit included the root mean squared error of approximation (RMSEA; parsimonious index) and the standardized root mean squared residual (SRMR; absolute index). Guidelines suggest that SRMR values less than or equal to 0.08 and

RMSEA values less than or equal to 0.06 are indicative of adequate data-model fit (Hu & Bentler, 1999). Indices for each model are shown in Table 19. Model fit was good for the statistical understanding model and adequate for the arithmetic model.

Table 20 shows a summary of the results for each model. For both the statistical understanding and arithmetic models, results indicated that the mean and variance of the intercept factor were significant for all conditions. The mean of the growth factor for both the statistical understanding and the arithmetic models was significant for both the board games and card games conditions, but not the literacy games condition. The variance of the growth factor was not significant for any condition. None of the parameters estimated for the differences between conditions were significant. Overall, this pattern of results indicates that children in the board game and card game conditions showed significant growth in statistical understanding and arithmetic, and children in the literacy games condition did not; however the differences in growth were not substantial enough to be significantly different across conditions.

Aim 1b

Aim 1b was to examine if there were differences in gains in statistical understanding based on the type of graphing game played (i.e., board game or card game). T-tests were used to compare pretest-posttest gains in interpreting graphs and constructing graphs in the board and card game conditions. Although the average gains in each condition followed the hypothesized pattern (i.e., Interpreting Graphs: $M_{\text{BoardGames}} = 0.64 < M_{\text{CardGames}} = 0.92$; Constructing Graphs: $M_{\text{BoardGames}} = 1.11 > M_{\text{CardGames}} = 0.76$), results indicated that there were no significant differences between the graphing game conditions in pretest-posttest gains in interpreting graphs (t(96)=-.794, p=.429, d=-.161) or constructing graphs (t(96)=.929, p=.355, d=.188).

Aim 2

The second aim was to examine if the numerical, mathematical, and statistical talk parents and children used during play related to gains in children's statistical understanding and math abilities. One-way ANOVAs were used as a preliminary analysis to examine differences in parent and child talk across conditions[2]. Results indicated that there were significant differences by condition in children's use of number words ($F(2, 101) = 20.98$, $p<.001$), math words ($F(2, 101) = 6.574$, $p = .002$), and stats words ($F(2, 101) = 11.72$, $p < .001$), and parents' use of number words ($F(2, 101) = 34.89$, $p < .001$), math words ($F(2, 101) = 51.31$, $p < .001$), and stats words ($F(2, 101) = 5.14$, $p = .007$). Specifically, comparisons for children's talk indicated that children in the graphing game conditions (i.e., board games and card games) had higher proportions of number and math talk than children in the literacy games condition. Children in the literacy games condition had a higher proportion of stats talk than children in the board and card games conditions, however proportions of stats talk in all conditions were approximately zero ($M_{\text{Board Games}} = .002$, $M_{\text{Card Games}} = .0003$, $M_{\text{Literacy Games}} = .006$).

For parents' number talk, results indicated that parents in the board game condition had higher proportions of number talk than parents in the card game and literacy game conditions. For parents' math talk, results indicated that parents in the card game condition had significantly higher proportions of math talk than parents in the board game and literacy game conditions, and parents in the board game condition had significantly higher proportions of math talk than parents in the literacy game condition. For parents' stats talk, similar to children's stats talk, results indicated that parents in the literacy games condition had significantly higher proportions

[2] Results are reported for proportions of talk. When analyses were conducted with total talk variables, the same overall pattern of results was observed.

of stats talk than parents in the card games condition, although proportions of stats talk in all conditions were approximately zero ($M_{\text{Board Games}}$ = .004, $M_{\text{Card Games}}$ = .001, $M_{\text{Literacy Games}}$ = .005).

To examine the relations of parent input with children's learning, correlations by condition between parent and child statistical**,** numerical, and mathematical talk and children's pretest-posttest gains on statistical understanding and math ability measures were used. Table 21 shows these correlations. For child talk, the math talk children in the board games condition used negatively related to gains in interpreting graphs, and math talk children in the card games condition used negatively related to gains in magnitude comparison. For parent talk, there were no significant correlations in the board games or literacy games conditions. In the card games condition, the math talk parents used negatively related to children's gains in arithmetic, and the stats talk parents used positively related to children's gains in statistical understanding and constructing graphs.

Additional Analyses

Additional analyses were conducted to further examine children's learning from the games. These included analyses examining dosage of gameplay, children's engagement and effort during the pretest and posttest sessions, and parent survey measures, as well as comparisons of subgroups of participants based on timeframe of completing the posttest and initial statistical understanding ability at pretest. Results for each of these analyses are reported in the following sections.

Dosage of Gameplay

To further examine relations of children's gameplay and learning, dosage of gameplay (e.g., total dates played and total minutes played) was examined in relation to children's pretest-posttest gain scores. Table 22 shows correlations between these variables, overall and by condition. Overall, dosage did not relate to pretest-posttest gains.

Child Engagement and Effort during Test Sessions

To further examine children's gains in statistical understanding, arithmetic, and magnitude comparison from pretest to posttest, gains were examined in relation to ratings the engagement and effort children demonstrated while completing the posttest measures. Table 23 shows correlations between gain scores and posttest engagement and effort ratings. Overall, engagement and effort positively related to gains in arithmetic and engagement negatively related to gains in magnitude comparison. For each condition, the same pattern was seen for the Card Games condition, and there were no significant relations between engagement, effort, and gains for the board games or literacy games conditions.

Parent Survey Measures

Relations between variables of interest and parent posttest survey measures were also examined to further understand patterns in children's learning from the games. Specifically, measures used from the posttest surveys included parent reports of their own and their child's enjoyment of the games, perception of their child's familiarity with concepts from the games (i.e., picture graphs, bar graphs, reading the axes of a graph or chart, comparing numerical magnitudes, letters and letter sounds, rhymes and rhyming words) prior to playing the games, and perception of changes in their child's understanding of these concepts over the four weeks of gameplay. Table 24 shows Spearman correlations between these and pretest-posttest gains, dosage of gameplay, and parent and child number, math, and stats talk.

Relations Between Survey Measures. Overall, parent and child enjoyment were significantly positively related. Parent and child enjoyment were also significantly related to perceived change in child's understanding of game concepts. Child enjoyment was also significantly related to dosage of gameplay.

For items about graphing skills, familiarity with the concepts was significantly negatively related to change in understanding of the concepts (e.g., parent perception of high familiarity before completing the study related to perception of lower changes in understanding after completing the study). Familiarity with picture graphs and bar graphs also significantly negatively related to dosage of gameplay.

Number, Math, and Stats Talk. For parent and child talk, familiarity with graphing concepts significantly positively related to child stats talk and significantly negatively related to parent math talk. Perceptions of change in understanding of graph concepts significantly positively related to parent and child number and math talk and negatively related to parent and child stats talk. Change in understanding of numerical magnitudes significantly negatively related to child stats talk and positively related to child number talk.

Pretest-Posttest Gains. For pretest-posttest gains, perceptions of change in understanding of bar graphs significantly positively related to gains on all measures of statistical understanding (total, interpreting graphs, constructing graphs). Perceptions of change in understanding of numerical magnitudes significantly positively related to gains in statistical understanding total scores. Change in understanding of letters/letter sounds significantly negatively related to gains in magnitude comparison, and change in understanding of rhymes/rhyming words significantly negatively related to gains in constructing graphs.

Condition Differences. One-way ANOVAs were used to examine differences in the enjoyment and familiarity variables across conditions. Results indicated that there were no differences in ratings of enjoyment or familiarity with game concepts ($F(2, 138) = .043$ to 2.960,

p = .055 to .958). Results from t-tests comparing the two graphing conditions to the literacy games condition showed the same pattern of results, with the exception that there were significant differences in familiarity with picture graphs ($t(139) = 2.189$, $p = .030$), with children in the literacy games condition having higher familiarity with picture graphs than children in the board and card games conditions.

Chi-square tests were used to examine differences in the change in understanding variables across conditions. Results indicated that there were significant differences in change in understanding between conditions in picture graphs ($\chi^2(4) = 50.172$, $p < .001$), bar graphs ($\chi^2(2) = 63.577$, $p < .001$), reading the axes of a graph or chart ($\chi^2(4) = 42.958$, $p < .001$), comparing numerical magnitudes ($\chi^2(4) = 14.846$, $p = .005$), letters/letter sounds ($\chi^2(2) = 6.119$, $p = .047$), and rhymes/rhyming words ($\chi^2(2) = 37.764$, $p < .001$). Results from chi-square tests comparing the graphing board game condition to the graphing card game condition indicated that there were no significant differences between the two conditions in any of the change in understanding variables (all $\chi^2(2)$s between .058 and 1.934, $p > .05$).

Considering Length of Time Between Test Sessions

Because there was wide variability in the length of time between pretest and posttest sessions, additional exploratory analyses were conducted to examine if there were differences in variables of interest based on the timeframe of completing the test sessions. Using the number of days between the start of Week 4 (the final week) of the intervention and completion of the posttest, the sample was divided into two groups based on the timeframe of the study. One group included participants ($n = 90$) who completed the posttest within 14 days of the start of Week 4 (i.e., within 1 week of completing the intervention, as planned in the study design), and the other group included participants (n = 58) who completed the posttest greater than 14 days after the start of Week 4 (range = 15 days to 63 days).

T-tests were used to compare the two groups' dosage of gameplay, enjoyment of the games, and ratings of pretest and posttest engagement and effort. For dosage of gameplay, results indicated that there were significant differences in total dates played ($t(140)=-6.008$, $p<.001$, $d=-1.309$) and total minutes played ($t(140)=-3.162$, $p=.002$, $d=-.547$), with participants who completed their posttest within the study timeframe playing more dates (M = 10.65) and more minutes (M = 192.96) than those who did not complete their posttest within the study timeframe (M = 7.06 and M = 138.62 respectively). For parent-reported enjoyment of the games, there were no significant differences in parent enjoyment ($t(139)=-.381$, $p=.704$, $d=-.066$), but there were significant differences in child enjoyment ($t(139)=-2.244$, $p=.026$, $d=-.393$), with participants who completed the posttest within the study timeframe reporting higher child enjoyment (M = 3.82) than those who did not (M = 3.42).

For ratings of effort and engagement during the test sessions, results indicated that there were no significant differences in pretest engagement ($t(146)=-1.449$, $p=.149$, $d=-.244$), pretest effort ($t(146)=-1.385$, $p=.168$, $d=-.233$), and posttest engagement ($t(146)=-1.054$, $p=.294$, $d=-.177$). There were significant differences in posttest effort ($t(146)=-2.363$, $p=.019$, $d=-.398$), such that participants who completed the posttest within the study timeframe had higher posttest effort (M = 4.50) than those who did not (M = 4.12).

T-tests were also used to examine differences in pretest-posttest gains by condition between the two groups, as a further examination of Aims 1a and 1b. For Aim 1a, one-sided t-tests were used because it was hypothesized that playing the graphing games would lead to greater gains than playing the literacy games. For participants who completed the posttest within the study timeframe there were no significant differences in gains between graphing and literacy conditions in statistical understanding total scores ($t(88)=-.942$, $p=.174$, $d=-.211$), interpreting graphs scores ($t(88)=-.490$, $p=.313$, $d=-.109$), constructing graphs scores ($t(88)=-.959$, $p=.170$, $d=-.214$), arithmetic ($t(88)=-1.143$, $p=.128$, $d=-.255$), or magnitude comparison ($t(88)=.343$, $p=.366$, $d=.077$).

For participants who did not complete the posttest within the study timeframe, there were no significant differences between graphing and literacy conditions in interpreting graphs scores ($t(56)=-1.232$, $p=.112$, $d=-.340$), constructing graphs scores ($t(56)=-1.550$, $p=.063$, $d=-.428$), arithmetic ($t(56)=-.036$, $p=.486$, $d=-.010$), or magnitude comparison ($t(55)=-1.028$, $p=.154$, $d=-.285$). There was a significant difference in statistical understanding total scores ($t(56)=-1.902$, $p=.031$, $d=-.525$), with participants in the graphing conditions ($M = 1.92$) having higher gains than those in the literacy condition ($M = 0.50$).

For Aim 1b, results indicated that there were no significant differences between the board games and card games conditions in gains in interpreting graphs[3] or constructing graphs for participants who completed the posttest within the study timeframe ($t_{\text{ConstructingGraphs}}(58)=.071$, $p=.472$, $d=.018$) and those who did not ($t_{\text{InterpretingGraphs}}(36)=-1.023$, $p=.313$, $d=-.334$; $t_{\text{ConstructingGraphs}}(36)=1.477$, $p=.148$, $d=.482$).

Considering Differences in Initial Statistical Understanding Ability

Because there was variability in children's pretest scores, additional exploratory analyses were conducted to examine differences in children's learning from the games based on differences in initial ability in statistical understanding. Consistent with previous studies that

[3] Because participants in the board game and card game conditions who completed the posttest within the study timeframe had the exact same average gains in interpreting graphs ($M_{Board} = 0.77$, $M_{Card} = 0.77$), a t-test was not conducted to examine differences in this measure.

have considered differences in children's learning from math games based on initial math ability level (Ramani & Siegler, 2011; Siegler & Ramani, 2009), to examine differences in initial ability participants were divided into two groups—one group with statistical understanding scores above the median at pretest and one group with statistical understanding scores below the median at pretest. Figure 13 shows average scores on interpreting graphs and constructing graphs questions at pretest and posttest for each group.

T-tests were used to compare the two groups' dosage of gameplay and enjoyment of the games. For dosage of gameplay, results indicated there were no significant differences in total dates played ($t(140)=.464$, $p=.643$, $d=.078$) or total minutes played ($t(140)=.708$, $p=.479$, $d=.119$). For parent-reported enjoyment of the games, results indicated that there were no significant differences in parent enjoyment ($t(139)=.464$, $p=.644$, $d=.078$) or child enjoyment ($t(138)=1.273$, $p=.205$, $d=.215$).

A multigroup second-order latent growth model was conducted to examine differences in statistical understanding from pretest to posttest. The same model was used as in Aim 1a (see Figure 11). To have adequate sample sizes in each group, the board and card games conditions were combined into one graphing condition, which was compared to the literacy games condition. In total, 4 groups were compared: (1) Graphing Condition, Low Initial Ability, (2) Graphing Condition, High Initial Ability, (3) Literacy Condition, Low Initial Ability, and (4) Literacy Condition, High Initial Ability. The model had good model fit, as indicated by the following indices, RMSEA = 0.000 (90% CI: 0.000 to 0.138), SRMR = 0.062, $\chi^2(10)=7.238$.

A summary of model results is shown in Table 25. Results indicated that the mean intercept factor was significant for all groups. The mean of the growth factor was significant for both the graphing games and literacy games groups with low initial ability, and was not significant for groups with high initial ability. The variance of the intercept factor was significant for the literacy games group with low initial ability, and was not significant for any other groups. The variance of the growth factor was not significant in any group.

For the parameters estimated for differences between groups, there were significant differences in the mean of the growth factor between the graphing condition low initial ability and graphing condition high ability groups, the graphing condition low initial ability and literacy condition high initial ability groups, the literacy condition low initial ability and graphing condition high initial ability groups, and the literacy condition low initial ability and literacy condition high initial ability groups. There were no significant differences between any groups in the variance of the growth factor. These results indicate that in both graphing and literacy conditions, children who started with lower initial ability showed significantly more growth in statistical understanding than children who started with higher initial ability.

Summary

Overall, the current study examined the role of a home-based graphing game intervention for children's statistical understanding and math abilities. Results showed that there was variability in children's initial statistical understanding and math abilities, dosage of gameplay, and parent and child use of number, math, and stats talk during play. Findings from the primary aims indicated that children who played graphing board games and graphing card games showed significant improvements in their statistical understanding and arithmetic abilities, and children who played literacy games did not, with the consideration that growth in the graphing games conditions was significant within condition but not substantial enough to be significant across the conditions (Aim 1a). In considering the role of graphing game type, results indicated that there were no differences between the graphing board game and card game conditions in gains in children's abilities to interpret and construct graphs (Aim 1b). Results also indicated that parent and child use of number, math, and stats talk during play primarily did not relate to gains in children's statistical understanding, arithmetic, or magnitude comparison abilities (Aim 2).

Results from additional, exploratory analyses also provide information about children's learning from the games and families' engagement in the games. In considering dosage of play, results showed that the number of days and minutes played did not relate to gains in children's abilities. Results from parent surveys indicated that parents and children enjoyed the games, and enjoyment did not differ across conditions. Parents also reported that their children were relatively unfamiliar with the graphing concepts prior to playing the games and that they perceived that their children understood more after playing the games. In considering the timeframe of completing the posttest, results showed differences based on the timeframe of completing the posttest. Specifically, for participants who completed the posttest outside of the study timeframe, children in graphing conditions had larger improvements than children in the literacy games condition. There were no significant differences in graphing and literacy conditions for children who completed the posttest within the study timeframe. Finally, in examining children's initial statistical understanding abilities, results indicated that children who started with lower initial statistical understanding abilities improved more than children who started with higher statistical understanding abilities.

Chapter 5: Discussion

Overall, the goal of the current study was to examine the role of a home-based graphing game intervention for children's statistical understanding and broader math abilities. Building on both classic developmental theories (Piaget, 1950; Vygotsky 1986) and recent theories of playful learning (Fisher et al., 2010; Zosh et al., 2018), the study aimed to examine: (1) if playing graphing games led to improvements in children's statistical understanding and math abilities, (2) if playing a board game versus a card game led to differences in improvements in children's abilities to interpret and construct graphs, and (3) if the numerical, mathematical, and statistical talk parents and children used during gameplay related to gains in children's statistical understanding and math abilities. The results of this study provide evidence that playing graphing games at home can improve children's statistical understanding abilities.

The current study extended previous research on the role of games for math learning in early childhood in several ways. First, previous research has focused primarily on games designed to promote children's numerical skills (e.g., Laski & Siegler, 2014; Ramani & Siegler, 2008), even though early math includes topics beyond number concepts. The current study is the first study to focus specifically on games designed to promote children's statistical understanding skills. Although statistical understanding is an application of children's foundational math skills and remains critical throughout the lifespan, there is limited research on children's statistical understanding skills in early childhood and few studies considering how to promote children's early skills in this area. The current study fills this gap in the literature both by examining games to promote statistical understanding and by providing descriptive information about children's early statistical understanding abilities.

Second, while previous studies have examined children's math learning from board games and card games separately (e.g., Cheung & McBride-Chang, 2015; Eloffson et al., 2016; Ramani & Scalise, 2020; Skillen et al., 2018), fewer studies have directly compared learning from different types of games. Because game structure and design can influence children's learning, it is important to consider how different types of games covering the same math content may promote learning differently. The current study compared children's learning of interpreting and constructing graphs from board games and card games. Overall, the study provides initial evidence on the role of graphing games for promoting children's statistical understanding and math abilities in early childhood, with implications for children's later development of statistical literacy and mathematical skills.

Role of Graphing Games for Children's Statistical Understanding and Math Abilities

Statistical Understanding

Overall, the findings provide preliminary evidence that playing graphing games can lead to improvements in children's statistical understanding abilities. Results from multigroup structural equation modeling analyses indicated that there was significant mean growth in statistical understanding for children in the board games and card games conditions, but not the literacy games condition, although growth did not differ across conditions. These results indicate that children who played the graphing games showed improvement in their graphing skills after completing the intervention. Overall, these results align with theories of playful learning which posit that children can learn from games and play (Fisher et al., 2010; Zosh et al., 2018). Results are also consistent with previous research indicating that playing math games in the home environment can support children's math learning (Benavides-Varela et al., 2016, Cheung & McBride, 2017; Mutaf Yildez et al., 2018; Niklas & Schneider, 2014; Ramani & Scalise, 2020;

Sonnenschein et al., 2016). The findings of the current study build on these findings by showing that games can support areas of math learning other than children's numerical skills, such as graphing.

Results from exploratory analyses also indicated that children whose statistical understanding ability was below the median at pretest improved more than children whose ability was above the median at pretest. Specifically, children with lower initial ability in the graphing conditions improved more than children with higher initial ability in the graphing and literacy conditions, and children with lower initial ability in the literacy condition improved more than children with higher initial ability in the literacy and graphing conditions. It is important to note that this pattern of improvements is not due to ceiling performance at pretest in the higher initial ability group. On average, children above the median at pretest answered 7.61 and 7.89 out of 9 questions correctly for interpreting graphs and constructing graphs, respectively. At posttest, average scores for this group were 7.72 and 8.12, respectively, indicating room for potential additional gains. Overall, these results suggest that for children who started with lower initial statistical understanding abilities, playing games (either graphing or literacy) with parents at home led to improvements in their statistical understanding abilities. This pattern of results is consistent with prior research indicating that after playing a numerical board game children with lower initial math ability levels improved more on math outcomes than children with higher initial ability levels (Ramani & Siegler, 2011; Siegler & Ramani, 2009).

In addition, exploratory analyses indicated that children who completed the posttest outside of the study timeframe (i.e., more than one week after the final week of the intervention) showed a different pattern of learning than children who completed the posttest within the study timeframe. Specifically, for participants who completed the posttest outside of the study timeframe, children in graphing conditions had larger improvements than children in the literacy games condition. In contrast, there were no significant differences in graphing and literacy conditions for children who completed the posttest within the study timeframe. This suggests the possibility that gains in statistical understanding may be seen over a longer period of time than the immediate posttest. These findings are also interesting given that children who did not complete the study within the suggested timeframe also had significantly lower dosage of gameplay than children who did complete the study within the timeframe. A pattern of lower dosage but higher gains from pretest to posttest suggests the possibility that other aspects of gameplay (e.g., quality of gameplay) may have differed between these groups as well, contributing to differences in learning.

Overall, these results contribute to the literature on children's early math development by considering their statistical understanding abilities. Few prior studies have examined this area of young children's math development, even though it is a central component of foundational math learning. The results of the current study provide both descriptive information about young children's abilities to construct and interpret graphs and information about the role of games in promoting these skills in early childhood. Because statistical understanding is a skill that remains essential throughout the lifespan, understanding how to support children's learning in this area is critical.

Math Abilities

Findings related to gains in children's math abilities were mixed. For arithmetic, results from multigroup structural equation modeling analyses indicated that there was significant mean growth in statistical understanding for children in the board games and card games conditions, but not the literacy games condition. These results indicate that children who played the graphing games showed improvement in their arithmetic skills after completing the intervention. Gains in magnitude comparison were more difficult to evaluate, as about 51% of participants answered 35 or 36 out of 36 items correctly at pretest. Model fit for the confirmatory factor analysis model was not adequate, so a growth model was not examined.

For arithmetic, these results add to the literature on math games supporting children's learning of math skills. Previous research has shown evidence that playing math games can promote children's arithmetic (Chao et al., 2000; Cheung & McBride, 2017; Elofsson et al., 2016; Guberman & Saxe, 2000; Ramani & Siegler, 2011), however, the games used in those studies targeted arithmetic skills more directly. In the current study, games targeted graphing skills, however, as graphing skills build on children's arithmetic skills, additional practice with graphing during gameplay can also provide additional practice with arithmetic as well.

It is important to note that while arithmetic could be incorporated into gameplay in multiple ways, arithmetic was not directly required to successfully play the games. For example, in the graphing board game, players could use arithmetic to determine how many total tiles they had in a category after adding tiles to their board on their turn (e.g., I had 3 yellow tiles and I added 2 more yellow tiles, and 3 plus 2 is five, so I have five yellow tiles now) as well as how many more tiles they needed to fill a certain category (e.g., I have 3 blue tiles and I need 10 blue tiles, 10 minus 3 is 7, so I need 7 more blue tiles), but these were not necessary to play the game. For the card game, players could use arithmetic to consider how many more or less players had in each of their category (e.g., my category has 5 votes and your category has 8 votes, 8 minus 5 is 3, so your category has 3 more votes than mine), but this was not necessary to play the game. In this way, gains in arithmetic after playing the games further demonstrate the connections between children's early graphing and children's early math skills.

Game Type

The current study also examined the type of graphing game (e.g., board game, card game) in relation to children's learning from the games. Because each graphing game was designed with specific features to promote children's abilities to interpret graphs (card games) or construct graphs (board games), it was expected that different game types could promote learning differently. Contrary to these predictions, findings indicated that there were no significant differences in gains in children's abilities to interpret or construct graphs between children who played graphing board games and children who played graphing card games. These findings suggest that playing graphing games can improve children's graphing skills more generally. In addition, it may be possible that practice with either skill (i.e., interpreting graphs or constructing graphs) during gameplay may transfer to the other skill. In this way, when children play a game focused on constructing graphs they could improve their abilities to construct graphs such that they are able to apply what they learn to their abilities to interpret graphs.

Role of Parent-Child Numerical, Mathematical, and Statistical Talk During Gameplay

The second aim of the study was focused on the numerical, mathematical, and statistical talk parents and children used during gameplay. Overall, there was wide variability in the amount of number, math, and stats talk parents and children used during their gameplay. This observation is consistent with variability reported in previous studies examining parent-child math talk (Levine et al., 2010; Ramani et al., 2015).

Of the categories of talk examined, parents and children used more number talk than math or stats talk. Within the category of number talk, the majority of numbers parents and children used were small numbers (numbers 0 to 10). This was unsurprising given the values represented in the game materials ranged from 0 to 10. Specifically, the number dice used in the board and literacy games included values 1, 2, and 3; the graphs shown in the board and card games depicted axes from 0 to 10; and the game boards for the board games condition had the data for the graph written at the top, which included the values 1, 2, 3, 5, 6, 7, 8, and 10. While all of these materials allowed for discussions of numbers larger than ten, these discussions were not required to play the games.

Overall, examinations of differences in talk by condition indicated that there were significant differences in parent and child number, math, and stats talk across conditions. Specifically, results indicated that children in the board and card games conditions used more number and math talk than children in the literacy games condition, and children in the literacy games condition used more stats talk than children in the board and card game conditions. Results were similar for parent talk, with parents in the board games condition using more number talk than parents in the other two conditions, and parents in the card games condition using more math talk than parents in the other two conditions. The results also showed that parents in the board games condition using more math talk than parents in the literacy games condition, and parents in the literacy games condition using more stats talk than parents in the card games condition.

Differences in number, math, and stats talk between the two graphing games conditions and literacy games condition were expected, as the math and stats content of the graphing games should elicit talk related to number, math, and stats, while the only aspect of the literacy game directly involving any of these concepts is the rolling of the dice to determine how many cards to draw. Considering this, the results indicating that participants in the literacy games condition used more stats talk than those in the graphing conditions were unexpected. It is important to note though, that the overall use of stats talk was very low, with the largest proportions of stats talk for parents and children both being 0.03. With this in mind, it is possible that this pattern of results is due to the natural use of words classified here as “statistical words,” including *row*, *column*, and *line*, in a non-statistical way. It is reasonable for parents and children in the literacy games condition to use these words during their gameplay to describe where matching rhyming words are on their boards (e.g., “Look in this *row*;” “It’s the second one in that *column*;” “In the first *line*.”). However, it is clear in these examples of participant talk that these words are not being used in a statistical way. Because the method for examining number, math, and stats talk in the current study was focused on the number of times each word was used (rather than the context in which each word was used), these differences in word usage were not captured in the current study.

In considering relations of parent and child math talk with gains in children’s statistical understanding and math abilities, it was expected that more frequent use of number, math, and stats talk would promote gains in children’s abilities. However, the results of the current study did not follow this pattern. In fact, few correlations between parent-child talk and gains were significant, and it is likely that any significant correlations were driven by a few parents and children using a substantially higher amount of talk than other participants, rather than being representative of overall trends in talk relating to gains in outcomes.

While prior research has considered the role of math talk for children’s math abilities, few prior studies have considered how math talk contributes to gains in children’s learning from math game interventions. In one study, Ramani and Scalise (2020) found that parent scaffolding and parent use of number words during play of a numerical magnitude game did not relate to gains in children’s math performance, but that parent use of number words during play of a shape game related to gains in children’s counting. The current study’s results are consistent with this finding, in that parent and child talk did not relate to gains in learning from the graphing games.

Further, findings from other studies of math talk provide additional evidence that relations between parent math talk and child math ability may also vary based on the content of talk. Studies have shown that parent talk about more advanced numerical concepts (e.g., cardinality, ordinal relations, arithmetic; Ramani et al., 2015), addition and subtraction (Vandermaas-Peeler et al., 2012) and larger numbers (e.g., numbers greater than 10; Elliott et al., 2017) relate to children's math ability, while talk about other foundational concepts, numerical skills, and smaller numbers does not. In the current study, talk was examined by considering the quantity of number, math, and stats words, rather than categorizing talk into talk about more or less advanced concepts within these domains. It is possible that talk about more advanced concepts (e.g., talk about arithmetic, what the data/numbers represent) may relate to children's learning, but this was not captured by the current study.

Dosage of Gameplay

The current study included gameplay logs as a measure of dosage, as understanding the amount of gameplay children participate in is important for understanding patterns in children's learning from the games. Compared to previous studies (Ramani & Scalise, 2020; Sonnenschein et al., 2016), the percent of gameplay logs returned (96%) was high. It is possible that offering families the option of completing the log on paper or online contributed to the higher percentage of returned logs.

Overall, there were wide ranges in the number of dates and number of minutes that families played the games. This replicates findings from previous home-based game intervention studies showing variability in dosage (Ramani & Scalise, 2020; Sonnenschein et al., 2016). In the current study, both the average number of dates played (9.3 days) and the average number of minutes played (172 minutes) were slightly lower than the suggested amount of gameplay (12 days / 180 minutes, respectively).

Overall findings indicated that dosage of gameplay was not correlated with pretest-posttest gains in children's statistical understanding or math abilities. Few previous studies have reported relations of dosage and learning gains. In one study, Ramani and Scalise (2020) found that the number of minutes (but not the number of times) families played a magnitude comparison game related to gains in children's magnitude comparison and number line skills, and there were no relations with gains in other math knowledge measures. They also found that for families who played a shape and color game, number of minutes played related to gains in children's shape finding, and number of times played related to gains in children's counting; there were no relations with gains in other math knowledge measures.

In the current study, it is possible that other factors beyond the amount of play may have been more important for children's learning from the games. For example, it is possible that the quality of the gameplay may be more important than the quantity of the gameplay, such that interactions during play, implementation fidelity in playing the games according to the game instructions, or other individual differences may have influenced children's learning from the games more than the number of times or minutes they played.

Exploratory analyses also indicated that dosage was positively related to parents' ratings of children's enjoyment of the games and was negatively related to parents' perception of children's familiarity with picture graphs and bar graphs before the intervention. These findings suggest the possibility that some of the variability in dosage may be due to parents adapting the amount of gameplay based on their perceptions of their children's playing and learning experiences.

Parent Survey Measures

After participants completed the posttest, parent survey measures were collected in order to provide further information about families' experiences playing the games during the intervention and parents' perceptions of children's skills before and after playing the games. The three sets of questions analyzed related to parent and child enjoyment of the games, parents' perceptions of children's familiarity with the game concepts prior to completing the study, and parents' perceptions of changes in children's understanding of the game concepts over the four weeks of playing the games.

Parent and Child Enjoyment

Overall, the majority of parents reported that they (55%) and their child (59%) enjoyed or really enjoyed the games. There were no significant differences in enjoyment across conditions, indicating that each of the games was considered enjoyable for parents and children. This is also important given the relations of enjoyment and dosage described above, as differences in enjoyment could impact how often families choose to play the games. In addition, for the graphing games, there were no differences in enjoyment of the games based on children's initial statistical understanding ability at pretest. This is important, as it suggests that each game was engaging regardless of initial ability. In contrast, if enjoyment had differed based on ability level, this could indicate that the content of the game was too easy or difficult based on children's initial understanding, which could make the games less engaging for children.

Results also indicated that parent and child enjoyment were significantly related to parents' perceptions of changes in children's understanding of the game concepts (e.g., picture graphs, reading axes of a graph or chart, comparing numerical magnitudes, letters/letter sounds, rhymes/rhyming words). This finding aligns with theories of playful learning, as engagement and joy are central components of how playful experiences promote learning (Zosh et al., 2018).

Perceptions of Familiarity and Change in Understanding of Game Concepts

Parents were asked to report their perceptions of how familiar their child was with the game concepts prior to playing the games as well as if they noticed changes in their child's understanding of the same concepts over the four weeks of playing the games.

For perceived familiarity, parents reported that children were relatively unfamiliar with graphing concepts before playing the games. Specifically, the percent of parents reporting that children were familiar/very familiar with each concept was the following: picture graphs (32%), bar graphs (28%), and reading the axes of a graph or chart (14%). In contrast, the majority of parents reported that children were familiar/very familiar with comparing numerical magnitudes (56%), letters and letter sounds (87%), and rhymes and rhyming words (86%). Lower levels of familiarity with graphing concepts are consistent with previous research indicating that data analysis and statistical literacy are not often a primary focus in early math instruction (English 2012; English 2013). Further, lower familiarity with these concepts highlights the need for additional methods, such as graphing games, for teaching graphing concepts in early childhood.

For perceptions of change in children's understanding, the majority (range: 76% to 87%) of parents in the board games and card games conditions reported that children understood each of the graphing concepts more after playing the games. This is important, as it indicates that parents noticed changes in their children's abilities and suggests that they viewed the games as effective for promoting learning of the concepts. Notably, parents' perceptions of children's change in understanding of bar graphs significantly related to children's actual pretest-posttest gains in statistical understanding (both overall and for interpreting graphs and constructing graphs scores). While the broader concepts (e.g., picture graphs, bar graphs) parents were asked to report on were not specifically individually measured in the statistical understanding measures, this finding suggests that parents' perceptions of changes in these broader concepts related to the overall concepts measured in the statistical understanding task.

Implementation Fidelity

The current study included multiple measures of implementation fidelity, specifically related to how often families played the games as described in the game instructions. Few previous math game intervention studies have reported measures of implementation fidelity; however, these measures can provide useful information about how children learn from the games. This is especially important when games are played in naturalistic settings, such as the home environment in the current study, as adherence to gameplay instructions has the potential to vary widely in these settings.

Overall, parent reports indicated that the majority of families (range 76% to 86%) played the games as instructed most or all of the times they played. In comparison to previous studies, this level of fidelity to gameplay instructions is high (Sonnenschein et al., 2016). Further, the experimenter coding of gameplay videos showed similar results, with the exception of the item evaluating whether families said what the numbers of tiles (board games) or number for their category (card games) represented. An example of this would be saying that the value 8 represents 8 fish at the zoo, for the graph showing animals seen at the zoo. For the board games videos, only 18% of families said this type of statement all of the time, and for the card games videos only 40% of families said this type of statement all of the time. These percentages are very low in contrast to those for the other items coded (range 63% to 80% following the given instruction “all of the time”).

It is possible that talking about what the values represented occurred less because it did not directly facilitate gameplay the way the other coded items did. For example, in the board games, saying how many tiles were added to the board may occur more naturally on each turn, as each dice roll indicates the number to be added. Similarly, considering the number of tiles needed for each category may be more relevant to gameplay, as having the correct number of tiles is needed in order to win the game. In contrast, considering what the numbers of tiles represents is not necessarily needed in order to play or win the game. The card games are parallel to this in that saying the number represented for each player and which category had more directly facilitate gameplay, whereas saying what those numbers represent is not required to play or win the game.

With these differences in mind, it is interesting to consider the importance of each of these aspects of gameplay for children’s learning of graphing skills. As graphing and data analysis are applications of children’s math skills that put numbers into context, it is possible that the contextual aspect of considering and discussing what the numbers on the graph represent may be particularly important for children’s learning. The current study was not designed to measure how the different components of gameplay (e.g., considerations of the numbers on each graph, what each number represents, etc.) each contribute to children’s learning from the games; however, this may be an area for future research.

It is also interesting to consider why parent-reported implementation fidelity differed from the experimenter-coded implementation fidelity for this item. It is possible that parents overestimated the frequency that they followed the game instructions for saying what the numbers represented. However, as it was only possible to code the gameplay of families who submitted videos of their play, it is also possible that some differences are due to missing data. In addition, as parents were only asked to upload one video of their gameplay over the four-week intervention, it is possible that implementation fidelity differed over different sessions of their gameplay.

Children's Engagement and Effort During Test Sessions

Children's engagement and effort during the pretest and posttest sessions were coded to examine any differences in performance and gains based on variability in children's participation in the test sessions. Overall, the results of the coding indicated that there was variability in children's engagement and effort, but on average, both engagement and effort were high at pretest (4.43 and 4.34 out of 5, respectively) and posttest (4.38 and 4.35 out of 5, respectively). Importantly, there were no differences between conditions in children's engagement and effort.

In considering posttest engagement and effort in relation to pretest-posttest gains, results indicated that both engagement and effort positively related to gains in arithmetic and engagement negatively related to gains in magnitude comparison. Because arithmetic was a more difficult task for children, it is possible that differences in engagement and effort influenced this measure more than others. For example, children with very low effort may have repeatedly said "I don't know" for problems they didn't automatically know the answers to, without trying to solve the problems first. Although the experimenters prompted children to provide answers, giving a numerical answer was not required (e.g., it was acceptable to say "I don't know"). Regarding gains in magnitude comparison, it is likely that this correlation was due to outliers. As pretest performance was at ceiling for the majority of the participants, the majority of participants had gains of 0 or 1, however the range of gains was -11 to 18.

Limitations

The current study has several limitations. Of these, multiple limitations relate to the nature of conducting developmental research online during a global pandemic. First, as all test sessions were conducted over Zoom, there was wide variability in the testing conditions for pretest and posttest sessions. Both within and between families, pretest and posttest sessions differed by time of day (e.g., early mornings vs. late evenings) depending on scheduling for the particular week of the test session, whether they were conducted during the school year or the summer, and whether children were viewing the measures on a computer, tablet, or phone screen. These have the potential to impact children's performance, as focus or motivation could change based on when, where, and how children were completing the sessions. In addition, viewing the items on a smaller versus larger screen could make it harder to answer questions if children relied on the smaller details of the visual images of the questions to generate their answers. For example, for the graphing questions, it may have been harder to see and/or count the small grid boxes on each graph on a smaller screen than a larger screen.

Between families there were also differences in other aspects of the test sessions. Families differed in parent presence and involvement during the test sessions, internet connection speed (resulting in different video/audio quality during the sessions), and familiarity and experience using Zoom. Children also completed the test sessions in different locations—including indoor spaces and outdoor spaces—all of which varied in level of background noise, frequency of others (e.g., parents, siblings, pets) coming through, and general potential for distractibility. These have the potential to influence children's ability to focus on completing the tasks during the pretest and posttest sessions, and notably seem to differ from completing similar testing in in-person lab, school, or museum settings where there would be more consistency between subjects in testing conditions. Regarding parent presence and involvement during the pretest session, this is particularly important to consider, as parents watching children complete the pretest could give parents more details of the focus of the study, and therefore potentially influence both how they completed the games with their children throughout the intervention weeks as well as if they coached or otherwise prepared their children prior to the posttest. During in-person testing settings, it may have been easier to control whether parents attended pretest sessions, to account for these potential differences in engagement in the study that could impact children's performance at posttest.

In addition, materials were presented to children over Zoom. While this approach is consistent with common methods for conducting online research (Chuey et al., 2021; Kominsky et al., 2021), it can be limiting in comparison to in-person methods in a few ways. For example, even with multiple checks built in, there is not necessarily a shared understanding between the experimenter and participant of what can be seen on the screen at all times, especially with lags in internet connections. In addition, in some ways the presentation of questions in the virtual format may require additional skills (e.g., executive functioning, verbal ability) for children to answer. In the current study, this is particularly relevant for the constructing graphs questions (i.e., graphing questions that were multiple choice). These questions were set up so that children could say the color of the graph (i.e., blue, green, purple) that was their answer. However, sometimes children would give other responses for their answers that didn't correspond to any one graph in particular (e.g., "red," "the cat", other elements of the axis labels, etc.), in some cases it was unclear whether children did not understand the graphing concept or simply did not have the ability to verbally clarify which graph they were talking about. If these questions were administered in an in-person setting or a more interactive virtual format, children could have pointed to or otherwise indicated which graph they were trying to select as their answer, without having to rely on their verbal or executive functioning skills to do so.

There was also considerable variability in the time between pretest and posttest for participants, including differences in the time it took for participants to receive their games in the mail after completing the pretest. While it was possible to examine differences between participants based on the timeframe of when they completed the posttest, the variability in the amount of time between the pretest and receiving the game materials was outside of the control of the study.

In addition, there was approximately 17% attrition (30 participants completed a pretest and received game materials, but did not complete a posttest). While this amount is relatively low in comparison to other home-based game intervention studies (Scalise et al., under review; Sonnenschein et al., 2016), it is still a sizeable amount. As a result, some of the analyses may be underpowered. While some factors impacting attrition are outside of control of the study (e.g., participant health and family emergencies, storms/natural disasters, impacts the COVID-19 pandemic), other aspects of the study could be changed to aim to reduce participant attrition. For example, reducing the suggested amount of gameplay (e.g., play 2 times/week instead of 3 times/week), further emphasizing that the suggested amounts are only suggestions (e.g., that families should feel free to play as little or as much as is feasible for them), and providing a larger amount of compensation for participants may make the study more feasible for families and help with participant retention. In addition, timing data collection such that data is collected either in the school year or in the summer (instead of both) could also potentially help, as family schedules may change during school year-summer transition times, making it more difficult for families to continue incorporating an extra task, such as gameplay.

Although steps were taken to reach and recruit a diverse sample of participants, the final sample was diverse in terms of geographic locations, however did not otherwise represent a diverse sample. The majority of participants were White, not Hispanic/Latino, had high household income, and were very highly educated. Future studies should aim to reach a more diverse sample of participants. This is especially important for understanding how children learn from the games and developing game materials that are enjoyable and accessible for children. For example, previous research with math games has shown that children from low-income backgrounds benefit more from playing math games than children from middle-income backgrounds (Ramani & Siegler, 2011). It is possible that different subgroups of children may learn differently from the games used in the current study, and understanding these differences is important for developing games to best support children's learning. In addition, due to the scope of the study and the resources available, the games and study materials were only developed in English. Future studies could expand this by developing game materials suitable for use in multiple languages, to further increase accessibility of the game materials for families of different language backgrounds.

Future Directions

The current study also opens several areas for future research. These include examining individual differences, parent-child interactions during play, children's problem-solving strategies, and the context and implementation of the intervention.

Individual Differences

Future work could consider the role of individual factors in relation to children's learning from the games and other aspects of families' engagement in the gameplay. Parent factors, such as math anxiety and attitudes and beliefs about math and learning through play have the potential to influence the amount of time parents engage in math gameplay with their children as well as the types of interactions they have with their children during gameplay. For example, parents may engage differently in the games based on whether they believe play should be more parent-led or child-led, as well as whether or not they believe play is an important context for children's learning. In addition, prior research has indicated that parent math anxiety influences children's learning when parents and children engage in math together in certain contexts (e.g., math homework; Maloney et al., 2015) but not others (e.g., math iPad app; Schaeffer et al., 2018). As the influence can be context-dependent, understanding how parent factors may influence children's learning from gameplay is important.

Further, studies could also consider parents' math and stats abilities as well. Given research suggesting that high school and college students struggle with interpreting and constructing graphs (Lapp & Cyrus, 2000; Leonard & Patterson, 2004; Padilla et al., 1986; Tairab & Al-Naqbi, 2004), it is possible that parents may also struggle in these areas. Although the games used in the current study focus on graphing content that is simple for adults (e.g., placing the same number of tiles that is written in the data into an empty graph template, comparing relative magnitudes of different categories), if parents vary in their understanding or confidence in their own abilities for these concepts, this has the potential to influence gameplay in multiple ways. First, parent ability could influence dosage of play or affect during play if they feel they do not understand enough to play the games. Second, previous research has shown that parent math ability relates to both parent and child use of advanced math talk during play (DePascale et al., 2021). In this way, it is also possible that parent abilities could influence the content of parent-child talk during play, which could further influence what and how children learn from the games.

Parent-Child Interactions During Play

Future work could also further examine aspects of parent-child interactions during gameplay. Specifically, the quality of the number, math, and stats talk parents and children use could be examined to further understand how talk may relate to children's learning. For example, interactions could be coded to examine the math content area of the talk (e.g., cardinality, arithmetic, magnitude comparison, graphing, use of numbers in context) as well as whether talk focuses on foundational or advanced math skills (Ramani et al., 2015). The type of guidance parents provide to children could also be examined (Bjorklund et al., 2004; Vandermaas-Peeler et al., 2012), as well as the types of questions children ask parents while playing the games. Further, parent and child engagement and affect could also be coded, as previous work has indicated that parent-child social engagement and connections, such as jokes and laughing, during play relate to children's math abilities (Vandermaas-Peeler & Pittard, 2014).

Children's Problem-Solving Strategies

Another area for future research would be to consider the types of strategies children use to solve the statistical understanding questions. Previous research on arithmetic has indicated that children use different strategies (e.g., counting, breaking problems down into different parts) to solve addition problems (Geary et al., 2004), and that children who use more sophisticated strategies to solve problems tend to solve problems more efficiently and accurately than those who use less sophisticated strategies (Bailey et al., 2012; Torbeyns et al., 2005; Vasilyeva et al., 2015). It is possible that the sophistication of strategies children use to solve graph problems relates to their graphing abilities and may also relate to their other math abilities as well. Examining children's strategy use would provide information about this, as well as if playing the games leads to changes in the sophistication of strategies children use.

Intervention Context and Implementation

Future studies could also include additional measures to further understand children's learning from the games. For example, studies could include an additional time point (e.g., delayed posttest) to examine if changes in children's abilities endure over time. Studies could also consider how children's learning from games compares to their learning from other materials or instructional activities (e.g., a worksheet). Understanding if and how children's learning differs between different playful (e.g., games) and direct instruction (e.g., worksheet) contexts would allow for a deeper understanding of the role of games in children's development of statistical understanding and math abilities.

In addition, studies could also consider the role of games in different settings or contexts of gameplay. The current study focused on games played by parents and children in the home environment. Future studies could examine games led by an experimenter, games led by a teacher in a school setting, or games played between groups or pairs of peer children. This would allow for an understanding of how learning may differ when games are played in different settings and with different co-players. In addition, play with an experimenter would allow for examining children's learning when other aspects of gameplay (e.g., dosage, guidance and feedback during play, adherence to game instructions) are kept constant.

To further examine influences on children's learning in the home environment, future research could examine how other aspects of the home environment, such as frequency of engaging in games and math activities at home, and how these activities and games compare to those used in the study, relate to children's learning from the games. Future studies could also examine if providing additional instructions or materials to parents (e.g., information about the importance of graphing and statistical literacy for children; suggestions for topics to discuss and/or guidance to provide to children while playing) prior to the intervention would influence parent and child talk during game play and children's learning from the games. In the current study, the mathematical focus of the study was not described to parents, in order to examine the role of games for math learning in an unbiased way. However, previous research has indicated that parent use of math talk during play is malleable to suggestions provided from researchers (Vandermaas-Peeler et al., 2012). Therefore, providing parents with suggested prompts or guidance has the potential to influence the quality of parent-child interactions during play and children's learning from the games. Similarly, it is also possible that discussing or providing information about the importance of graphing and statistical literacy with parents prior to the study could influence how parents choose to engage in the games with their children.

Finally, as many children demonstrated a high performance on the pretest measures, future studies could aim to accommodate this in multiple ways. First, studies could use pretest measures or other measures to screen children's initial ability, prior to participation in the intervention. In this way, the intervention would be targeted to children who have the most potential to benefit from playing the games. Alternatively, the intervention could incorporate games with different levels to be used based on children's abilities. For example, the card games could include additional levels such as having players (1) compare whose category had the least, (2) each choose multiple categories and compare the sum of their categories, (3) draw multiple cards and compare their color's category across different graphs. Further, if game instructions include guidance to parents of content to talk about during play, these could include levels as well, such as prompts for general gameplay and prompts for an extra challenge. In this way, children would have the opportunity to engage in the games in a way that is both enjoyable and appropriately challenging for them, regardless of initial ability level.

Implications and Applications

The current study contributes to the field by providing initial evidence on how games can promote children's early understanding of graphs and data analysis, which are a critical part of children's early numerical understanding. Although data analysis and measurement are considered an important component of children's early math learning, there is limited research examining children's data analysis skills in early childhood and methods for promoting skills in this area. Findings from the current study provide evidence on the role of games to further engage and promote children in their learning of these essential skills.

The current study also has several implications and applications for families and educators. First, the results provide preliminary evidence that children can improve their graphing skills through playing games with parents at home. Because graphing and early data analysis skills are essential for children's math development and later statistical literacy, the use of games to further engage children and promote their learning of these skills is important.

Further, parents' reports of children's low familiarity with graphing concepts highlight the importance of further incorporating statistical literacy activities and instruction into children's early learning experiences. The types of games used in the current study could be incorporated into classroom or home activities to engage children in their learning of these concepts, in a playful, enjoyable way.

Finally, the current study has applications for increasing family engagement in math at home. Providing math games for families to use at home has the potential to increase children's math learning through play-based parent-child interactions. In addition, as parents reported noticing changes in their children's understanding of graphing and math concepts over a relatively short duration of play, the study has the potential to increase children's early math engagement at home, by highlighting the role of games and playful interactions in children's math learning and development.

Conclusion

Basic statistical literacy is essential for understanding and making inferences from information received from external sources and for developing critical thinking skills necessary for engagement in real-world contexts throughout the lifespan. Although math games are known to be an effective method for instruction in early childhood, the current study is the first to examine the role of games for mathematical topics beyond early numerical skills, specifically statistical understanding. The findings provide preliminary evidence that children can learn from playing graphing games with parents at home, as well as descriptive information about children's early statistical understanding skills and parent and child engagement in graphing games at home. These results can support the development of future play-based interventions and materials to promote children's early mathematical and statistical skills, with implications for children's later development and achievement.

Tables and Figures

Table 1

Participant Age and Game Characteristics of Included Articles

Study	Age	Game Type	Game Content	Game Context
Chao, Stigler, & Woodward (2000)	Kindergarten	Set of Games	Basic	School
Cheung & McBride-Chang (2015)	Daycare	Card Game	Advanced	Home
Cheung & McBride (2017)	Kindergarten	Board Game	Advanced	Home
Dillon, Kannan, Dea, Spelke, & Duflo (2017)	Preschool	Set of Games	Basic	School
Elofsson, Gustafson, Samuelsson, & Traff (2016)	Preschool	Board Game	Advanced	School
Guberman & Saxe (2000)	3rd-4th Grade	Board Game	Advanced	School
Jirout, Holmes, Ramsook, & Newcombe (2018)	K – 2nd Grade	Physical Game	Advanced	School
Laski & Siegler (2014)	Kindergarten	Board Game	Advanced	School
Loehr & Rittle-Johnson (2017)	3rd-4th Grade	Card Game	Advanced	School
Navarrete, Gomez, & Dartnell (2018)	Preschool	Physical Game	Basic	School
Ramani & Scalise (2020)	Preschool	Card Game	Advanced	Home
Ramani & Siegler (2008)	Preschool	Board Game	Basic	School
Ramani & Siegler (2011)	Preschool	Board Game	Basic	School
Ramani, Siegler, & Hitti (2012)	Preschool	Board Game	Basic	School
Scalise, Daubert, & Ramani (2018)	Preschool	Card Game	Advanced	School
Siegler & Ramani (2008)	Preschool	Board Game	Basic	School
Siegler & Ramani (2009)	Preschool	Board Game	Basic	School
Skillen, Berner, & Seitz-Stein (2018)	Kindergarten	Board Game	Advanced	School
Sonnenschein, Metzger, Dowling, Gay, & Simmons (2016)	Preschool	Board Game	Advanced	Home
Van Herwegen, Costa, & Passolunghi (2017)	Preschool	Set of Games	Basic	School
Vandermaas-Peeler & Pittard (2014)	Preschool	Board Game	Basic	Home
Vandermaas-Peeler, Ferretti, & Loving (2012)	Preschool	Board Game	Basic	Home
Whyte & Bull (2008)	Preschool	Board Game, Card Game	Advanced	School

Table 2

Summary of Dosage of Gameplay

Study	Type	Dosage
Chao, Stigler, & Woodward (2000)	Intervention	5 weeks
Cheung & McBride-Chang (2015)	Intervention	10 weeks
Cheung & McBride (2017)	Intervention	4 weeks
Dillon, Kannan, Dea, Spelke, & Duflo (2017)	Intervention	4 months
Elofsson, Gustafson, Samuelsson, & Traff (2016)	Intervention	3 weeks
Guberman & Saxe (2000)	Intervention	2.5 months
Jirout, Holmes, Ramsook, & Newcombe (2018)	Single Time Point	~12 minutes
Laski & Siegler (2014)	Intervention	3 weeks
Loehr & Rittle-Johnson (2017)	Single Time Point	< 40 minutes
Navarrete, Gomez, & Dartnell (2018)	Intervention	8 weeks
Ramani & Scalise (2020)	Intervention	6 weeks
Ramani & Siegler (2008)	Intervention	2 weeks
Ramani & Siegler (2011)	Intervention	3 weeks
Ramani, Siegler, & Hitti (2012)	Intervention	3-4 weeks
Scalise, Daubert, & Ramani (2018)	Intervention	3 weeks
Siegler & Ramani (2008)	Intervention	2 weeks
Siegler & Ramani (2009)	Intervention	3 weeks
Skillen, Berner, & Seitz-Stein (2018)	Intervention	4 weeks
Sonnenschein, Metzger, Dowling, Gay, & Simmons (2016)	Intervention	5 weeks
Van Herwegen, Costa, & Passolunghi (2017)	Intervention	5 weeks
Vandermaas-Peeler & Pittard (2014)	Single Time Point	15 minutes
Vandermaas-Peeler, Ferretti, & Loving (2012)	Intervention	2 weeks
Whyte & Bull (2008)	Intervention	4 weeks

Table 3

Summary of Math Outcome Measures Studied

Study	Counting	Numeral Identification	Magnitude Comparison	Number Line Estimation	Arithmetic	Cardinality	Math Interest	Non-symbolic Number	Place Value/ Base Ten
Chao, Stigler, & Woodward (2000)	*	*	*		<u>X</u>, *			*	X
Cheung & McBride-Chang (2015)	<u>X</u>	<u>X</u>	<u>X</u>		X				
Cheung & McBride (2017)	<u>X</u>	<u>X</u>			<u>X</u>		<u>X</u>		
Dillon, Kannan, Dea, Spelke, & Duflo (2017)		<u>*</u>						<u>*</u>	
Elofsson, Gustafson, Samuelsson, & Traff (2016)	X	<u>X</u>		<u>X</u>	<u>X</u>				
Guberman & Saxe (2000)					<u>X</u>				
Jirout, Holmes, Ramsook, & Newcombe (2018)				<u>X</u>					
Laski & Siegler (2014)	<u>X</u>	<u>X</u>		<u>X</u>					
Loehr & Rittle-Johnson (2017)		X	<u>X</u>	<u>X</u>					<u>X</u>
Navarrete, Gomez, & Dartnell (2018)	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>					
Ramani & Scalise (2020)	X	X	<u>X</u>	<u>X</u>		X			
Ramani & Siegler (2008)	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>					
Ramani & Siegler (2011)	X	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>				
Ramani, Siegler, & Hitti (2012)	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>					
Scalise, Daubert, & Ramani (2018)	<u>X</u>	<u>X</u>	<u>X</u>					<u>X</u>	
Siegler & Ramani (2008)				<u>X</u>					
Siegler & Ramani (2009)	X	<u>X</u>	<u>X</u>	<u>X</u>	<u>X</u>				
Skillen, Berner, & Seitz-Stein (2018)	<u>*</u>	<u>*</u>	<u>*</u>						
Sonnenschein, Metzger, Dowling, Gay, & Simmons (2016)	<u>X</u>	<u>X</u>	X	<u>X</u>					

Van Herwegen, Costa, & Passolunghi (2017)						X
Vandermaas-Peeler & Pittard (2014)	*	*	*		*	*
Vandermaas-Peeler, Ferretti, & Loving (2012)	*	*	*		*	*
Whyte & Bull (2008)	X	X	X	X		

Note: X indicates outcomes measured directly, * indicates that the outcome was measured as part of a standardized math assessment
Underlined measures indicate that children showed significant improvement on the measure after playing a math game

Table 4

Descriptive Statistics of Demographic Survey Variables

	Full Sample *n* = 148	Board Games *n* = 47	Card Games *n* = 51	Literacy Games *n* = 50	Attrition (did not complete posttest) *n* = 30
Child Age in Months, *M* (*SD*)	71.14 (6.59)	71.21 (5.93)	70.51 (7.17)	71.55 (6.60)	70.73 (6.28)
[min, max]	[59, 83]	[60, 83]	[60, 83]	[59, 83]	[60, 82]
Gender, *n* (%)					
Female	74 (50)	22 (46.8)	28 (54.9)	24 (48)	15 (50)
Male	74 (50)	25 (53.2)	23 (45.1)	26 (52)	15 (50)
Child Race, *n* (%)					
African American or Black	5 (3.4)	1 (2.1)	1 (2)	3 (6)	1 (3.3)
White	99 (66.9)	31 (66)	37 (72.5)	31 (62)	18 (60)
Asian American or Pacific Islander	18 (12.2)	7 (14.9)	4 (7.8)	7 (14)	2 (6.7)
American Indian or Alaska Native	1 (0.7)	1 (2.1)	0 (0)	0 (0)	0 (0)
Biracial/Mixed Race	12 (8.1)	3 (6.4)	4 (7.8)	5 (10)	5 (16.7)
Other	11 (7.6)	3 (6.3)	4 (7.9)	4 (8)	1 (3.3)
Missing	2 (1.4)	1 (2.1)	1 (2)	0 (0)	1 (3.3)
Child Ethnicity, *n* (%)					
Hispanic or Latino	16 (10.8)	3 (6.4)	7 (13.7)	6 (12)	8 (26.7)
Not Hispanic or Latino	131 (88.5)	44 (93.6)	43 (84.3)	44 (88)	22 (73.3)
Missing	1 (0.7)	0 (0)	1 (2)	0 (0)	0 (0)
Parent Race, *n* (%)					
African American or Black	6 (4.1)	2 (4.3)	1 (2)	3 (6)	1 (3.3)
White	106 (71.6)	33 (70.2)	40 (78.4)	33 (66)	23 (76.7)
Asian American or Pacific Islander	26 (17.6)	8 (17)	8 (15.7)	10 (20)	2 (6.7)
American Indian or Alaska Native	1 (0.7)	1 (2.1)	0 (0)	0 (0)	0 (0)
Biracial/Mixed Race	8 (5.4)	3 (6.4)	1 (2)	4 (8)	2 (6.7)
Other	1 (0.7)	0 (0)	1 (2)	0 (0)	1 (3.3)
Parent Ethnicity, *n* (%)					
Hispanic or Latino	9 (6.1)	3 (6.4)	3 (5.9)	3 (6)	4 (13.3)
Not Hispanic or Latino	139 (93.9)	44 (93.6)	48 (94.1)	47 (94)	26 (86.7)

Languages Spoken at Home, *n* (%)					
English only	112 (75.7)	35 (74.5)	37 (72.5)	40 (80)	24 (80)
Spanish only	0 (0)	0 (0)	0 (0)	0 (0)	1 (3.3)
English and Spanish	6 (4.1)	1 (2.1)	4 (7.8)	1 (2)	3 (10)
English, Spanish, and Other	3 (2)	0 (0)	1 (2)	2 (4)	0 (0)
English and French	3 (2)	1 (2.1)	1 (2)	1 (2)	0 (0)
English, French, and Other	1 (0.7)	1 (2.1)	0 (0)	0 (0)	0 (0)
English and Other	21 (14.2)	8 (17)	8 (15.7)	5 (10)	1 (3.3)
Other[a]	2 (1.4)	1 (2.1)	0 (0)	1 (2)	1 (3.3)
Parent 1 Education, *n* (%)					
Some high school	0 (0)	0 (0)	0 (0)	0 (0)	1 (3.3)
High school diploma/GED	1 (0.7)	1 (2.1)	0 (0)	0 (0)	2 (6.7)
Some college coursework/vocational training	6 (4.1)	2 (4.3)	1 (2)	3 (6)	4 (13.3)
2-year college degree (Associates)	4 (2.7)	1 (2.1)	2 (3.9)	1 (2)	2 (6.7)
4-year college degree (BA/BS)	47 (31.8)	12 (25.5)	22 (43.1)	13 (26)	5 (16.7)
Postgraduate or professional degree (MA, PhD, MD, JD)	89 (60.1)	31 (66.0)	25 (49.0)	33 (66)	16 (53.3)
Missing	1 (0.7)	0 (0)	1 (2)	0 (0)	0 (0)
Parent 2 Education, *n* (%)					
Some high school	1 (0.7)	1 (2.1)	0 (0)	0 (0)	0 (0)
High school diploma/GED	3 (2)	1 (2.1)	1 (2)	1 (2)	6 (20)
Some college coursework/vocational training	9 (6.1)	3 (6.4)	5 (9.8)	1 (2)	8 (26.7)
2-year college degree (Associates)	5 (3.4)	0 (0)	3 (5.9)	2 (4)	2 (6.7)
4-year college degree (BA/BS)	51 (34.5)	16 (34)	13 (25.5)	22 (44)	6 (20)
Postgraduate or professional degree (MA, PhD, MD, JD)	75 (50.7)	25 (53.2)	27 (52.9)	23 (46)	7 (23.3)
Missing	4 (2.7)	1 (2.1)	2 (3.9)	1 (2)	1 (3.3)
Annual Household Income, *n* (%)					
Less than \$15,000	2 (1.4)	0 (0)	1 (2)	1 (2)	1 (3.3)
\$15,000 to \$30,000	3 (2)	0 (0)	2 (3.9)	1 (2)	2 (6.7)

$31,000 to $45,000	5 (3.4)	2 (4.3)	2 (3.9)	1 (2)	3 (10)
$46,000 to $59,000	5 (3.4)	2 (4.3)	1 (2)	2 (4)	1 (3.3)
$60,000 to $75,000	15 (10.1)	6 (12.8)	6 (11.8)	3 (6)	3 (10)
$76,000 to $100,000	18 (12.2)	5 (10.6)	7 (13.7)	6 (12)	3 (10)
$101,000 to $150,000	41 (27.7)	12 (25.5)	17 (33.3)	12 (24)	8 (26.7)
$151,000 or more	57 (38.5)	19 (40.4)	15 (29.4)	23 (46)	4 (13.3)
Missing	2 (1.4)	1 (2.1)	0 (0)	1 (2)	8 (26.7)
School Experience, *n* (%)					
PreK	31 (20.9)	6 (12.8)	15 (29.4)	10 (20)	8 (26.7)
Kindergarten	67 (45.3)	21 (44.7)	17 (33.3)	29 (58)	12 (40)
First Grade	16 (10.8)	6 (12.8)	6 (11.8)	4 (8)	2 (6.7)
Kindergarten or First Grade and Other	4 (2.7)	1 (2.1)	2 (4)	1 (2)	2 (6.7)
Other[b]	21 (14.2)	9 (19.1)	7 (13.7)	5 (10)	3 (10)
Missing	9 (6.1)	4 (8.5)	4 (7.8)	1 (2)	3 (10)
School Type, *n* (%)					
Public School	71 (48)	19 (40.4)	25 (49)	27 (54)	13 (43.3)
Charter School	9 (6.1)	1 (2.1)	4 (7.8)	4 (8)	3 (10)
Private School	27 (18.2)	10 (21.3)	6 (11.8)	11 (22)	7 (23.3)
Public School and Other	3 (2)	2 (4.3)	0 (0)	1 (2)	0 (0)
Other[c]	27 (18.2)	11 (23.4)	10 (19.6)	6 (12)	5 (16.7)
Missing	11 (7.4)	4 (8.5)	6 (11.8)	1 (2)	2 (6.7)
School Format, *n* (%)					
In Person	60 (40.5)	20 (42.6)	21 (41.2)	19 (38)	15 (50)
Virtually / Online	28 (18.9)	6 (12.8)	8 (15.7)	14 (28)	7 (23.3)
Hybrid (in person and online)	20 (13.5)	7 (14.9)	8 (15.7)	5 (10)	4 (13.3)
In Person and Other	12 (8.2)	3 (6.4)	3 (5.9)	6 (12)	0 (0)
Other[d]	23 (15.5)	9 (19.1)	9 (17.6)	5 (10)	2 (6.7)
Missing	5 (3.4)	2 (4.3)	2 (3.9)	1 (2)	2 (6.7)

[a]"Other" languages spoken at home included: Tamil, Mandarin, Norwegian, Korean, Italian, Russian, German, Hindi, Marathi, Gujarati, Finnish, Arabic, Chinese, Ukrainian, Swedish, Portuguese, Kannada, Vietnamese, and Croatian
[b]"Other" school experiences included: Preschool, Outschool classes, Homeschool, Homeschool due to the pandemic, Pod school, Summer break/summer camp
[c]"Other" school types included: School "pod", Homeschool, Preschool, Private preschool, PreK daycare, Child development center, Religious/church-based school, Kumon, and No school due to COVID
[d]"Other" school formats included: Home, Homeschool and Zoom, Not in school, and Started school year online and ended year with in person

Table 5

Summary of Study Design

Session	1		n/a	2	
Description	Pretest		Intervention (4 weeks)	Immediate Posttest	
Measures /Activities	Child	Parent	Child & Parent	Child	Parent
	• Statistical understanding • Math ability	• Demographic questionnaire	Play game together at least 3x per week	• Statistical understanding • Math ability	• Parent posttest survey

Table 6

Summary of Game Content by Condition and Weeks

Condition	Weeks 1-2	Weeks 3-4
Graphing Card Game	Picture Graphs	Bar Graphs
Graphing Board Game	Picture Graphs	Bar Graphs
Literacy Board Game	Alphabet/Letter Sounds	Rhyming Words

Table 7

Game Features Designed to Support Children's Graphing Abilities

Game Type	Game Feature	Description
Card Games	Representations of magnitude	The goal of the game is to use the magnitudes represented on the graph to interpret information about the graph (e.g., which category has more). In the current card game, children can see the magnitude of the categories on the graph in three ways, (1) by considering the amount of space each bar or set of objects occupies for each category, (2) by counting the number of discrete objects or grid spaces there are for each category, and (3) by reading the corresponding numeral for each category on the axis of the graph. In the same way that multiple representations of magnitude promote children's magnitude understanding in other card games (Chao et al., 2000; Ramani & Scalise, 2020; Scalise et al., 2017), the representations of magnitude within the graphs on the cards in the current study are expected to promote children's abilities as well.
Card Games	Parent feedback	When parents and children determine who wins each card, parents can provide feedback on children's magnitude comparisons. Parent feedback is expected to promote children's abilities to interpret graphs through the specific feedback on children's correct and incorrect comparisons.
Card Games	Increased exposure to graphs of familiar subjects/contexts	Each deck of cards includes 25 cards, each featuring a different graph. Throughout the intervention, children will be exposed to 50 graphs (e.g., 25 from each game). This increased exposure to graphs may assist with generalizing their skills across different graphs and contexts. Further, each graph depicted is based on a context that is familiar to children (e.g., foods, animals at the zoo, favorites, etc.). These will provide children with examples of the purpose of graphs.
Board Games	Inclusion of graphing context	The game board has both a graph template as well as a written graph context (i.e., written description of data). Displaying each of these together highlights the

	(i.e., written description of data)	connection of graphs and collected data, and playing the game to construct the graph based on the context makes this connection more explicit. This emphasis and process help children further understand that graphs are used to represent values/magnitudes.
Board Games	Direct practice constructing a graph from data	On each turn, children will have to consider the number of items that are supposed to be represented in each category and consider this in relation to what is currently represented on their graph game board. This will provide direct practice with using given data to construct a graph. Further, to successfully complete their graph, children can use numerical skills, such as counting, magnitude comparison, and arithmetic. As each of these skills is an important part of creating and interpreting graphs, the practice with these skills during gameplay is expected to promote their abilities.
Board Games	Highlights features of graphs	The structure of the game board highlights elements important for constructing graphs, including starting markings for each category at zero on the axis, the necessity to represent each category individually on the graph, and the correspondence of one unit of data to one unit of representation on the graph. These elements in concert with the practice of filling in the graph based on the provided context are expected to specifically promote children's abilities to make graphs.

Note: Card Games features are designed to promote interpretation of graphs, and Board Games features are designed to promote construction of graphs from data.

Table 8

Parent-Reported Implementation Fidelity

Condition	Item	Mean	SD
Card Games		-	-
Item 1	Read the title of the graph on each card out loud.	3.45	.80
Item 2	Say the number of your color's category out loud	3.47	.72
Item 3	Say what the number of your color's category represented (e.g., "There are 6 chocolate cupcakes at the bakery")	3.34	.79
Item 4	Ask your child to say which color/category had more.	3.40	.88
Board Games		-	-
Item 1	Read the description of the graph context (at the top of the board out loud)	2.87	.82
Item 2	Say the number and animal/color of tiles you added out loud (e.g., "3 giraffes)	3.47	.72
Item 3	Say what the tiles you added represented (e.g., "I added 2 giraffe tiles, which shows that they saw 2 giraffes at the zoo.")	2.66	.87
Item 4	Count the number of tiles in each category	3.21	.93
Literacy Games		-	-
Item 1	Say the label of the picture on the card out loud (e.g., "Watermelon") (Alphabet Matching)	3.37	.81
Item 2	Say the first letter of the item in the picture out loud (e.g., "W"). (Alphabet Matching)	3.14	.89
Item 3	Read the word on the card out loud (e.g., "Net"). (Rhyme Matching)	3.41	.81
Item 4	Say the rhyme match out loud when adding cards to the board (e.g., "Net rhymes with wet.") (Rhyme Matching)	3.31	.82

Note: For each condition, parents responded to the prompt "When playing the games, how often did you and your child…" and rated items on the following scale: (1) Never, (2) Some of the times we played, (3) Most of the times we played, (4) Every time we played

Table 9

Implementation Fidelity Coding

***Game*, Items Coded**	Did not occur *n* (%)	Occurred some of the time *n* (%)	Occurred all the time *n* (%)
Board Games			
1. Players say how many tiles they added (e.g., “2 purple”)	2 (5%)	10 (26%)	26 (68%)
2. Players say what the tiles represent (e.g., “2 children wore purple”)	7 (18%)	24 (63%)	7 (18%)
3. Players consider number of tiles needed based on graph description—(a) if a player exceeds the number needed in the graph description, they discard extra tiles, or (b) if a player rolls a color category that they no longer need based on the graph description, they skip their turn.	3 (8%)	9 (24%)	26 (68%)
Card Games			
1. Players say out loud the number represented on the graph for their color (e.g., “8 green”)	1 (3%)	6 (17%)	28 (80%)
2. Players say what the number for their category represents (e.g., “8 fish at the zoo”)	9 (26%)	12 (34%)	14 (40%)
3. Parent asks child / child independently states which category has more	1 (3%)	12 (34%)	22 (64%)

Table 10

Definitions of Engagement and Effort Ratings for Pretest and Posttest Sessions

Rating		Definition
Engagement		
1	Not at all engaged	The child is not attentive or on task at all. They may be getting up or moving around a lot, talking to others around them or playing with toys unrelated to the tasks, staring into space, or playing with Zoom. They do not return to the task after repeated prompting. They take much longer than the allotted time to complete the task.
2	Not engaged	Child is not attentive or on task a majority of the time. They are frequently distracted and need repeated prompting to get on task. They may be talking to others around them, playing with toys unrelated to the tasks, or playing with Zoom some of the time. There are a few moments where the child will be on task.
3	Okay	Child is engaged about 50% of the time. They may stay on task for a bit and then get distracted. They return to the task with some prompting.
4	Engaged	Child is attentive and on task the majority of the session. They need prompting to stay on task only a few times. They may get distracted briefly, but quickly get back on task.
5	Very Engaged	Child was attentive and on task throughout the entire session. Child may talk to themselves or others around them but the talk focuses on the task. They need little or no prompting to continue.
Effort		
1	Very low	The child is putting in very little or no effort. They may give nonsense/incorrect answers on purpose, may take a long time to respond (without trying to solve the problems), or may repeatedly say “I don’t know” without trying.
2	Low	The child is putting in little effort. They may give some incorrect answers on purpose, or say “this is too easy” or “I don’t know” (without trying) instead of answering questions a few times.
3	Moderate	The child’s effort level varies throughout the session, containing some elements of high/low effort.
4	High	The child is putting in effort a majority of the time. They are actively thinking/figuring out and responding to most questions.
5	Very high	The child is consistently putting in effort. They respond to questions or are actively thinking/figuring out their response.

Table 11

Summary of Data-Model Fit for Measurement Models

Model	df	χ^2	RMSEA [90% CI]	SRMR
Statistical Understanding	7	2.782	0.000 [0.000, 0.073]	0.033
Arithmetic	33	42.314	0.076 [0.000, 0.137]	0.053
Magnitude Comparison	75	224.283	0.202 [0.171, 0.232]	0.274

Table 12

Descriptive Statistics of Pretest and Posttest Measures, by Condition

	Board Games					Card Games					Literacy Games				
***Time,* Measure**	***n***	***M***	***SD***	**min**	**max**	***n***	***M***	***SD***	**min**	**max**	***n***	***M***	***SD***	**min**	**max**
Pretest															
Statistical Understanding (Overall)	47	11.15	4.61	2	18	51	11.10	4.86	2	18	50	11.84	5.10	1	18
Statistical Understanding (Interpreting Graphs)	47	5.77	2.33	1	9	51	5.59	2.56	0	9	50	5.98	2.39	0	9
Statistical Understanding (Constructing Graphs)	47	5.38	2.62	0	9	51	5.51	2.69	0	9	50	5.86	2.99	0	9
Arithmetic	47	10.34	7.43	0	21	51	9.59	7.19	0	21	50	12.08	6.94	0	21
Magnitude Comparison	47	32.36	5.11	16	36	51	29.90	7.17	3	36	50	32.06	5.47	17	36
Posttest															
Statistical Understanding (Overall)	47	12.89	4.22	3	18	51	12.78	4.73	3	18	50	12.64	4.99	2	18
Statistical Understanding (Interpreting Graphs)	47	6.40	2.17	1	9	51	6.51	2.21	1	9	50	6.40	2.47	1	9
Statistical Understanding (Constructing Graphs)	47	6.49	2.33	0	9	51	6.27	7.74	0	9	50	6.24	2.99	0	9
Arithmetic	47	11.09	7.35	0	21	51	10.39	7.41	0	21	50	12.46	6.92	0	21
Magnitude Comparison	47	32.47	5.03	19	36	50	30.54	5.84	15	36	50	32.18	6.03	12	36
Pretest-Posttest Gains															
Statistical Understanding (Overall)	47	1.74	2.84	-3	10	51	1.69	2.63	-5	10	50	0.80	2.76	-12	8
Statistical Understanding (Interpreting Graphs)	47	0.64	1.59	-2	5	51	0.92	1.91	-3	9	50	0.42	1.57	-5	3
Statistical Understanding (Constructing Graphs)	47	1.11	2.06	-3	6	51	0.76	1.57	-2	4	50	0.38	1.96	-7	5

Arithmetic	47	0.74	2.40	-8	6	51	0.80	2.59	-5	8	50	0.38	2.47	-8	5
Magnitude Comparison	47	0.11	1.95	-6	5	50	0.74	3.79	-11	18	50	0.12	1.92	-8	5

Table 13

Descriptive Statistics of Time Between Test Sessions

	M	*SD*	*Range*
Overall (*n* = 148)			
Days Pretest to Posttest	40.78	12.18	24 to 86
Days Week 4 to Posttest	16.04	11.17	4 to 63
Board Games (*n* = 47)			
Days Pretest to Posttest	39.19	11.26	27 to 73
Days Week 4 to Posttest	14.04	10.06	5 to 49
Card Games (*n* = 51)			
Days Pretest to Posttest	40.92	13.86	26 to 86
Days Week 4 to Posttest	16.35	12.33	5 to 63
Literacy Games (*n* = 50)			
Days Pretest to Posttest	42.14	11.20	24 to 68
Days Week 4 to Posttest	17.60	10.84	4 to 43

Table 14

Descriptive Statistics of Parent and Child Number, Math, and Stats Talk, Overall and by Condition

	Child				Parent				Other Speakers			
	n	*M*	*SD*	*Range*	*n*	*M*	*SD*	*Range*	*n*	*M*	*SD*	*Range*
Overall												
Total Number	104	52.25	39.68	1 to 238	104	47.98	32.60	3 to 141	18	12.50	19.48	0 to 70
Total Math	104	4.38	4.10	0 to 20	104	17.62	17.66	0 to 84	18	0.67	1.03	0 to 3
Total Stats	104	1.10	2.21	0 to 14	104	2.46	3.61	0 to 19	18	0.28	0.75	0 to 3
Proportion Number	104	0.13	0.09	0.01 to 0.53	104	0.06	0.04	0 to 0.21	18	0.05	0.05	0 to 0.13
Proportion Math	104	0.01	0.01	0 to 0.05	104	0.02	0.02	0 to 0.08	18	0.01	0.03	0 to 0.11
Proportion Stats	104	0	0.01	0 to 0.03	104	0	0	0 to 0.03	18	0	0.01	0 to 0.02
Board Games												
Total Number	38	61.24	26.86	2 to 141	38	75.08	30.97	15 to 141	4	15.25	19.36	1 to 42
Total Math	38	6.18	4.26	0 to 20	38	16.45	12.46	0 to 53	4	1.00	1.41	0 to 3
Total Stats	38	1.18	2.70	0 to 14	38	3.53	5.12	0 to 19	4	0	0	0 to 0
Proportion Number	38	0.14	0.06	0.03 to 0.29	38	0.10	0.04	0.05 to 0.21	4	0.07	0.05	0.02 to 0.13
Proportion Math	38	0.01	0.01	0 to 0.03	38	0.02	0.01	0 to 0.04	4	0	0	0 to 0.01
Proportion Stats	38	0	0	0 to 0.02	38	0	0.01	0 to 0.02	4	0	0	0 to 0
Card Games (*n* = 36)												
Total Number	36	67.50	48.10	11 to 238	36	37.44	24.98	4 to 117	7	19.43	26.86	0 to 70
Total Math	36	4.33	3.47	0 to 14	36	30.33	20.17	3 to 84	7	0.71	1.25	0 to 3
Total Stats	36	0.14	0.59	0 to 3	36	1.00	1.31	0 to 5	7	0	0	0 to 0
Proportion Number	36	0.19	0.11	0.06 to 0.53	36	0.05	0.03	0 to 0.15	7	0.05	0.06	0 to 0.13
Proportion Math	36	0.01	0.01	0 to 0.04	36	0.04	0.02	0.01 to 0.08	7	0.02	0.04	0 to 0.11
Proportion Stats	36	0	0	0 to 0	36	0	0	0 to 0.01	7	0	0	0 to 0
Literacy Games												
Total Number	30	22.57	23.92	1 to 105	30	26.30	14.52	3 to 68	7	4.00	4.62	0 to 11

Total Math	30	2.17	3.54	0 to 14	30	3.87	4.56	0 to 22	7	0.43	0.53	0 to 1
Total Stats	30	2.13	2.30	0 to 8	30	2.87	2.52	0 to 10	7	0.71	1.11	0 to 3
Proportion Number	30	0.06	0.05	0.01 to 0.19	30	0.04	0.03	0.01 to 0.14	7	0.03	0.04	0 to 0.10
Proportion Math	30	0.01	0.01	0 to 0.05	30	0	0.01	0 to 0.02	7	0	0	0 to 0.01
Proportion Stats	30	0.01	0.01	0 to 0.03	30	0	0.01	0 to 0.03	7	0.01	0.01	0 to 0.02

Table 15

Dosage of Gameplay by Condition

Variable, Condition	*n*	min	max	*M*	*SD*
Total Dates Played					
Board Games	45	1	13	9.60	3.34
Card Games	48	0	16	9.52	4.24
Literacy Games	49	0	16	8.76	3.95
Total Minutes Played					
Board Games	45	0	267	163.55	70.62
Card Games	48	0	710	171.06	110.88
Literacy Games	49	0	585	181.54	118.79

Table 16

Descriptive Statistics of Pretest and Posttest Engagement and Effort Ratings, by Condition

	Board Games (*n* = 47)				Card Games (*n* = 51)				Literacy Games (*n* = 51)			
***Time*, Measure**	***M***	***SD***	**min**	**max**	***M***	***SD***	**min**	**max**	***M***	***SD***	**min**	**max**
Pretest												
Engagement	4.34	1.048	1	5	4.35	0.955	1	5	4.58	0.642	3	5
Effort	4.36	0.919	2	5	4.12	1.125	1	5	4.56	0.812	2	5
Posttest												
Engagement	4.47	0.856	2	5	4.08	1.197	1	5	4.60	0.639	3	5
Effort	4.49	0.831	2	5	4.12	1.143	1	5	4.46	0.862	2	5

Table 17

Posttest Parent Survey Items (Enjoyment and Familiarity)

		Board Games			Card Games			Literacy Games		
Item	Description	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Enjoyment[a]	Please rate how much you and your child enjoyed the games.	-	-	-	-	-	-	-	-	-
Item 1	How much did you enjoy the games?	47	3.68	0.86	46	3.54	0.86	48	3.5	0.85
Item 2	How much did your child enjoy the games?	46	3.85	1.05	46	3.5	0.81	48	3.67	1.16
Familiarity[b]	Please indicate how familiar your child was with the following concepts prior to playing the games.	-	-	-	-	-	-	-	-	-
Item 1	Picture graphs	47	2.94	1.11	46	2.67	1.23	48	3.5	0.85
Item 2	Bar graphs	47	2.79	1.10	46	2.65	1.30	48	3.67	1.16
Item 3	Reading the axes of a graph or chart	47	2.36	1.05	46	2.33	1.30	48	3.27	1.23
Item 4	Comparing numerical magnitudes	47	3.74	1.19	46	3.5	1.28	48	2.94	1.16
Item 5	Letters and letter sounds	47	4.51	0.80	46	4.54	0.72	48	2.4	1.09
Item 6	Rhymes and rhyming words	47	4.43	0.83	46	4.43	0.66	48	3.6	1.27

[a]Enjoyment items were rated on the following scale: (1) Really did not enjoy the games, (2) Did not enjoy the games, (3) The games were okay, (4) Enjoyed the games, (5) Really enjoyed the games.
[b]Familiarity items were rated on the following scale: (1) Very unfamiliar, (2) Unfamiliar, (3) Somewhat familiar, (4) Familiar, (5) Very familiar.

Table 18

Posttest Parent Survey Items (Change in Understanding)

	Board Games				Card Games				Literacy Games			
Item, Rating[a]	-1	0	1	Missing	-1	0	1	Missing	-1	0	1	Missing
Picture graphs, *n* (%)	0 (0)	11 (23.4)	35 (74.5)	1 (2.1)	1 (2)	7 (13.7)	37 (72.5)	6 (11.8)	0 (0)	33 (66)	6 (12)	11 (22)
Bar graphs, *n* (%)	0 (0)	6 (12.8)	40 (85.1)	1 (2.1)	0 (0)	7 (13.7)	39 (76.5)	5 (9.8)	0 (0)	34 (68)	5 (10)	11 (22)
Reading the axes of a graph or chart, *n* (%)	1 (2.1)	9 (19.1)	36 (76.6)	1 (2.1)	0 (0)	9 (17.6)	34 (66.7)	8 (15.7)	0 (0)	32 (64)	8 (16)	10 (20)
Comparing numerical magnitudes, *n* (%)	0 (0)	27 (57.4)	19 (40.4)	1 (2.1)	1 (2)	23 (45.1)	21 (41.2)	6 (11.8)	0 (0)	35 (70)	5 (10)	10 (20)
Letters and letter sounds, *n* (%)	0 (0)	38 (80.9)	6 (12.8)	3 (6.4)	0 (0)	37 (72.5)	5 (9.8)	9 (17.6)	0 (0)	32 (64)	14 (28)	4 (8)
Rhymes and rhyming words, *n* (%)	0 (0)	40 (85.1)	3 (6.4)	4 (8.5)	0 (0)	38 (74.5)	5 (9.8)	8 (15.7)	0 (0)	19 (38)	27 (54)	4 (8)

[a]All items were in response to the question: "Please indicate if you noticed changes in your child's understanding of the following concepts over the 4 weeks" and were rated on the following scale: (-1) My child understood less after playing the games, (0) My child's understanding did not change after playing the games, (1) My child understood more after playing the games, (NA) Not applicable

Table 19

Summary of Data-Model Fit for Growth Models

Model	df	χ^2	RMSEA [90% CI]	SRMR
Statistical Understanding	7	2.787	0.000 [0.000, 0.073]	0.033
Arithmetic	33	42.314	0.076 [0.000, 0.137]	0.053

Table 20

Summary of Growth Model Results

	Board Games			Card Games			Literacy Games			$D_{Board–Card}$			$D_{Board–Literacy}$			$D_{Card–Literacy}$		
	Est.	SE	*p*	Est.	SE	*p*	Est.	SE	*p*	Est.	SE	*p*	Est.	SE	*p*	Est.	SE	*p*
Statistical Understanding																		
$M_{Intercept}$	5.721	0.318	<.001**	5.771	0.308	<.001**	5.997	0.329	<.001**	-0.050	0.424	.906	-0.277	0.445	.534	-0.226	0.439	.606
$Var_{Intercept}$	3.712	1.321	.005**	3.624	1.239	.003**	4.621	1.577	.003**	0.088	0.927	.925	-0.909	1.077	.399	-0.997	1.099	.364
M_{Growth}	0.769	0.196	<.001**	0.725	0.240	.002**	0.372	0.190	.050	0.044	0.280	.875	0.397	0.259	.124	0.353	0.259	.172
Var_{Growth}	0.493	0.395	.212	0.386	0.316	.222	0.549	0.744	.460	0.107	0.465	.818	-0.057	0.819	.945	-0.164	0.789	.835
Arithmetic																		
$M_{Intercept}$	2.443	0.282	<.001**	2.282	0.259	<.001**	2.754	0.250	<.001**	0.161	0.380	.672	-0.311	0.371	.403	-0.472	0.358	.187
$Var_{Intercept}$	3.163	0.376	<.001**	2.983	0.323	<.001**	2.815	0.422	<.001**	0.180	0.484	.710	0.348	0.568	.540	0.168	0.542	.756
M_{Growth}	0.192	0.086	.026*	0.195	0.092	0.034*	0.103	0.082	.211	-0.003	0.125	.978	0.089	0.118	.451	0.093	0.122	.448
Var_{Growth}	-0.029	0.108	.786	0.150	0.109	.171	0.053	0.091	.559	-0.179	0.153	.242	-0.083	0.141	.559	0.096	0.143	.500

*p<.05, **p<.01

Table 21

Correlations by Condition of Parent and Child Talk with Pretest-Posttest Gains in Statistical Understanding and Math Ability Measures

	Board Games						Card Games						Literacy Games					
	Child			Parent			Child			Parent			Child			Parent		
	Number Talk	Math Talk	Stats Talk	Number Talk	Math Talk	Stats Talk	Number Talk	Math Talk	Stats Talk	Number Talk	Math Talk	Stats Talk	Number Talk	Math Talk	Stats Talk	Number Talk	Math Talk	Stats Talk
Statistical Understanding	.022	-.310	-.118	-.216	.066	-.116	-.053	-.183	.169	-.180	-.057	.345*	.196	-.013	-.135	.166	.051	.085
Interpreting Graphs	.175	-.348*	-.109	-.313	-.021	.008	-.001	-.093	.082	-.017	-.056	.186	.152	-.024	.136	.262	.167	-.066
Constructing Graphs	-.106	-.155	-.077	-.053	.107	-.166	-.082	-.189	.179	-.265	-.029	.343*	.182	-.002	-.296	.059	-.043	.172
Arithmetic	.067	-.157	.181	.288	-.175	-.239	-.016	.122	-.086	-.482**	.112	-.061	.218	-.004	-.146	.165	.143	.088
Magnitude Comparison	.191	.054	.034	-.048	.082	.195	.333*	-.349*	-.025	-.113	.139	-.023	.218	.111	-.217	-.196	.174	-.240

*p<.05, **p<.01

Table 22

Correlations between Dosage of Gameplay and Pretest-Posttest Gains

	Overall		Board Games		Card Games		Literacy Games	
	Dates Played	Minutes Played	Dates Played	Minutes Played	Dates Played	Minutes Played	Dates Played	Minutes Played
Statistical Understanding	.054	.016	-.121	-.178	.088	.049	.118	.125
Interpreting Graphs	.102	.012	.034	.010	.072	-.047	.169	.093
Constructing Graphs	-.013	.013	-.193	-.253	.060	.145	.033	.104
Arithmetic	-.046	-.070	.120	.013	-.103	-.095	-.137	-.082
Magnitude Comparison	-.086	-.126	.000	.075	-.084	-.112	-.209	-.295*

*p<.05

Table 23

Correlations Between Children's Posttest Engagement and Effort Ratings and Pretest-Posttest Gains

	Overall		Board Games		Card Games		Literacy Games	
	Engagement	Effort	Engagement	Effort	Engagement	Effort	Engagement	Effort
Engagement	-		-		-		-	
Effort	.734**	-	.588**	-	.826**	-	.674**	-
Statistical Understanding	0.003	0.005	-0.003	-0.029	0.046	0.039	0.046	0.031
Interpreting Graphs	-0.017	-0.014	0.047	-0.044	0.003	0.014	-0.012	0.035
Constructing Graphs	0.021	0.02	-0.041	-0.006	0.074	0.049	0.075	0.015
Arithmetic	.182*	.186*	0.197	0.217	.295*	.318*	0.046	0.012
Magnitude Comparison	-.215**	-0.142	-0.083	-0.06	-.354*	-0.252	0.239	0.138

*p<.05, **p<.01

Table 24

Spearman Correlations between Parent Survey Measures, Pretest-Posttest Gains, Dosage, and Parent and Child Talk

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
Enjoyment														
1. Parent Enjoyment	-													
2. Child Enjoyment	.559**	-												
Familiarity with Game Concepts														
3. Familiarity (Picture graphs)	0.081	0.051	-											
4. Familiarity (Bar graphs)	0.045	0.016	.872**	-										
5. Familiarity (Reading the axes of a graph or chart)	0.044	0.039	.753**	.849**	-									
6. Familiarity (Comparing numerical magnitudes)	-0.16	0.003	.476**	.466**	.444**	-								
7. Familiarity (Letters and letter sounds)	-0.04	0.002	.320**	.336**	.381**	.456**	-							
8. Familiarity (Rhymes and rhyming words)	-0.01	-0.01	.394**	.391**	.434**	.415**	.687**	-						
Change in Understanding of Game Concepts														
9. Change (Picture graphs)	.248**	.199*	-.357**	-.303**	-.270**	-.194*	-0.14	-0.09	-					
10. Change (Bar graphs)	0.128	0.148	-.317**	-.262**	-.244**	-0.14	-.173*	-0.12	.860**	-				
11. Change (Reading the axes of a graph or chart)	.210*	0.155	-.260**	-.224*	-.259**	-.177*	-.175*	-0.13	.759**	.807**	-			
12. Change (Comparing numerical magnitudes)	.452**	.245**	-.246**	-.209*	-.252**	-.419**	-.234**	-0.14	.543**	.456**	.433**	-		
13. Change (Letters and letter sounds)	.200*	.210*	-0.07	-0.07	-0.01	-.214*	-.242**	-.214*	0.084	0.004	0.057	.320**	-	
14. Change (Rhymes and rhyming words)	.185*	.241**	0.048	-0.02	0.006	-0.17	-0.01	-0.13	-.223*	-.330**	-.215*	0.106	.651**	-
Pretest-Posttest Gains														
15. Statistical Understanding	0.078	0.116	-0.15	-0.16	-0.1	-0.13	0.019	0.001	0.155	.253**	0.152	.176*	-0.1	-0.17
16. Interpreting Graphs	0.015	0.069	-0.15	-0.11	-0.1	-0.12	0.028	-0.04	0.109	.174*	0.136	0.142	-0.12	-0.02
17. Constructing Graphs	0.046	0.095	-0.09	-0.13	-0.06	-0.07	-0.06	-0.03	0.099	.193*	0.067	0.103	-0.04	-.215*
18. Arithmetic	0.078	0.039	-0.05	-0.11	-0.12	-0.14	-.192*	-0.15	0.069	0.106	0.131	0.105	-0.05	-0.04
19. Magnitude Comparison	-0.1	-0.12	-0.06	-0.02	-0.02	0.076	0.01	-0.11	0.035	0.046	-0.04	0.032	-.208*	-0.09
Dosage														
20. Dates Played	0.068	.205*	-.195*	-0.12	0.004	-0.02	0.099	0.03	0.108	0.126	0.157	0.048	0.092	0.069
21. Minutes Played	0.061	.274**	-.263**	-.201*	-0.09	-0.08	0.11	0.008	0.063	0.067	0.113	0.038	0.109	0.158

Number, Math, and Stats Talk														
22. Child Number Talk (Proportion)	-0.03	-0.08	-.273**	-.200*	-.217*	-0.13	-.272**	-0.17	.301**	.392**	.261*	.244*	-0.15	-.318**
23. Child Math Talk (Proportion)	-0	-0.11	-0.08	-0	-0.05	-0.08	-0.17	-0.07	.229*	.308**	0.169	0.069	-0.19	-.220*
24. Child Stats Talk (Proportion)	0.003	0.176	.254**	.243*	.233*	0.121	0.153	0.126	-.354**	-.389**	-.300**	-.257*	0.03	.262**
25. Parent Number Talk (Proportion)	0.098	0.059	-0.01	0.053	0.023	0.027	-0.06	-0.01	.226*	.294**	.331**	0.109	0.094	-0.2
26. Parent Math Talk (Proportion)	-0.03	-0.08	-.260**	-0.19	-.221*	-0.08	-0.15	-0.05	.421**	.460**	.353**	0.169	-.294**	-.362**
27. Parent Stats Talk (Proportion)	-0.07	0.018	0.187	0.164	0.176	0.16	.206*	0.132	-.312**	-.271**	-.265**	-0.19	0.156	.233*

*p<.05, **p<.01

Table 25

Summary of Model Results (Differences in Initial Statistical Understanding Ability)

	$M_{\text{Intercept}}$			M_{Growth}			$\text{Var}_{\text{Intercept}}$			$\text{Var}_{\text{Growth}}$		
	Est.	SE	*p*	Est.	SE	*p*	Est.	SE	*p*	Est.	SE	*p*
Graphing Games, Low Initial Ability (G0)	4.121	0.217	<.001**	1.211	0.170	<.001**	0.564	0.331	.088	0.290	0.309	.348
Graphing Games, High Initial Ability (G1)	7.602	0.134	<.001**	0.208	0.130	.110	0.161	0.124	.193	0.074	0.217	.734
Literacy Games, Low Initial Ability (L0)	3.626	0.362	<.001**	0.818	0.258	.002**	1.568	0.590	.008**	0.175	0.566	.757
Literacy Games, High Initial Ability (L1)	7.643	0.145	<.001**	0.058	0.231	.802	0.051	0.133	.702	0.616	0.944	.514
$D_{G0–G1}$	-3.482	0.260	<.001**	1.003	0.212	<.001**	0.403	0.349	.249	0.216	0.377	.566
$D_{G0–L0}$	0.495	0.367	.178	0.394	0.303	.194	-1.004	0.657	.127	0.114	0.645	.859
$D_{G0–L1}$	-3.522	0.260	<.001**	1.153	0.290	<.001**	0.513	0.355	.148	-0.326	0.989	.742
$D_{G1–L0}$	3.977	0.388	<.001**	-0.609	0.287	.034*	-1.407	0.598	.019*	-0.102	0.607	.867
$D_{G1–L1}$	0.040	0.171	.814	0.150	0.267	.573	0.110	0.182	.544	-0.542	0.968	.575
$D_{L0–L1}$	-4.017	0.387	<.001**	0.760	0.348	.029*	1.518	0.603	.012*	-0.440	1.101	.689

*p<.05, **p<.01

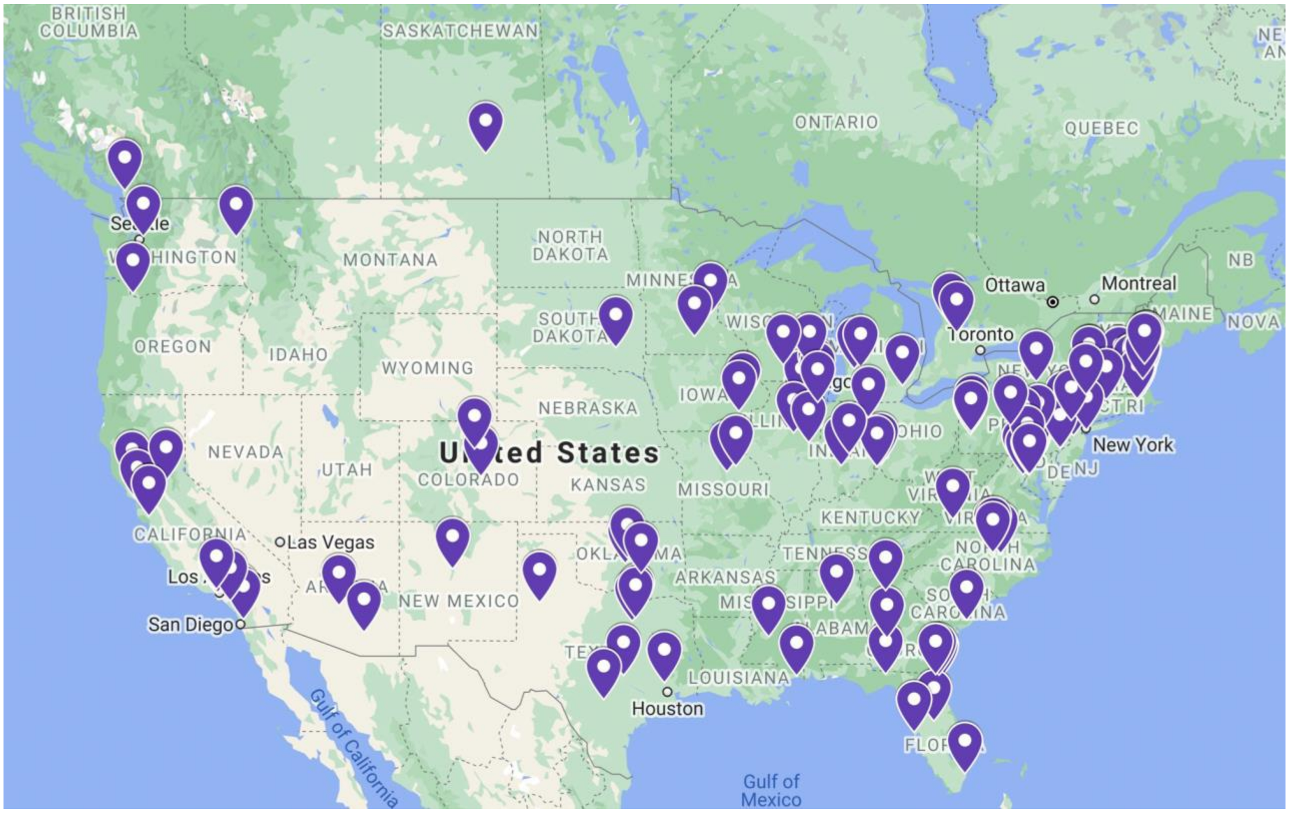


Figure 1. Map of participant geographic locations. Participation was limited to participants living in the United States (n=144) and Canada (n=4).

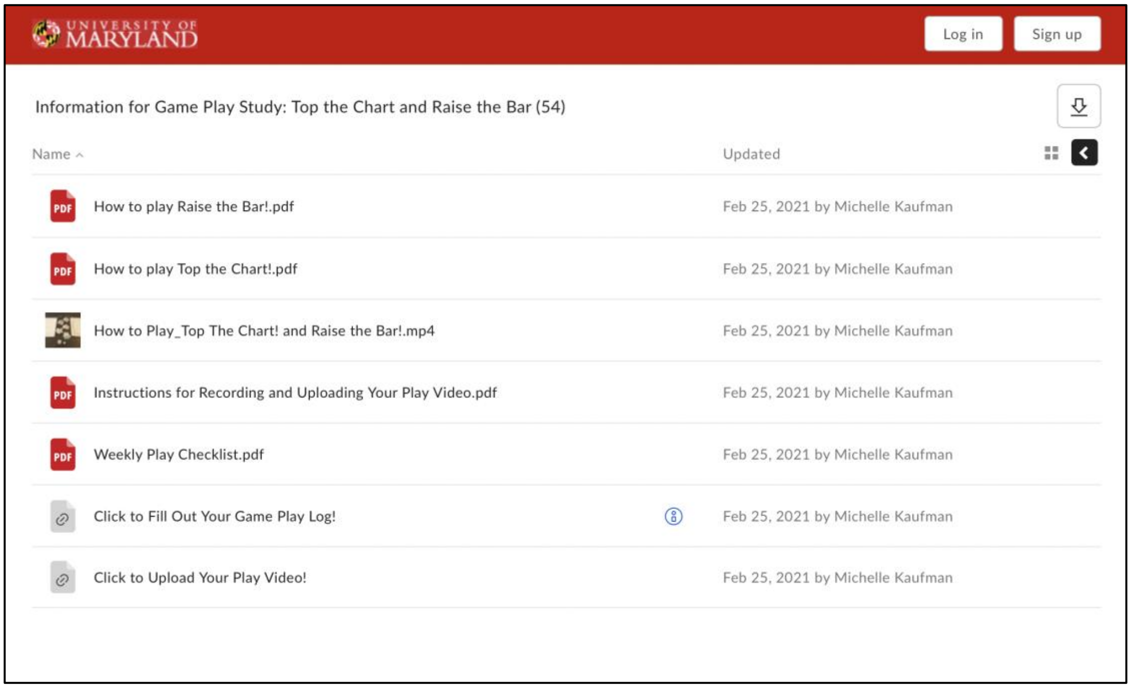


Figure 2. Example participant personal online Box folder containing written game instructions, video game instructions, instructions for recording and uploading a play video, a weekly play checklist, and links to fill out their game play log and upload their play video to the folder.

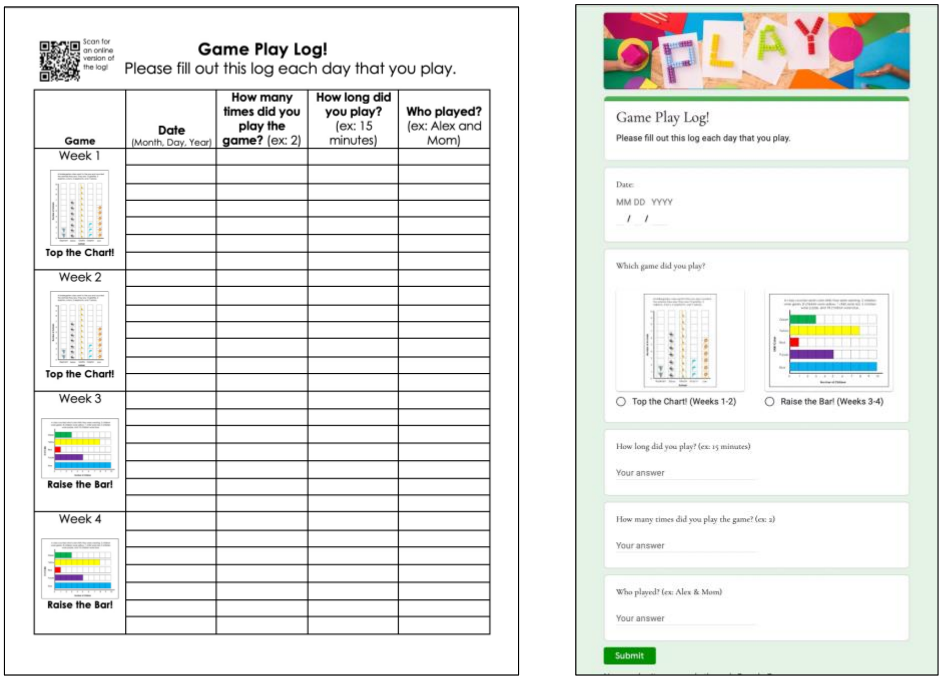


Figure 3. Example paper game play log with QR code (left) to access online game play log google form (right). Families were asked to record the date, how many times they played, how long they played for, and who played, and could use either or both formats of the log.

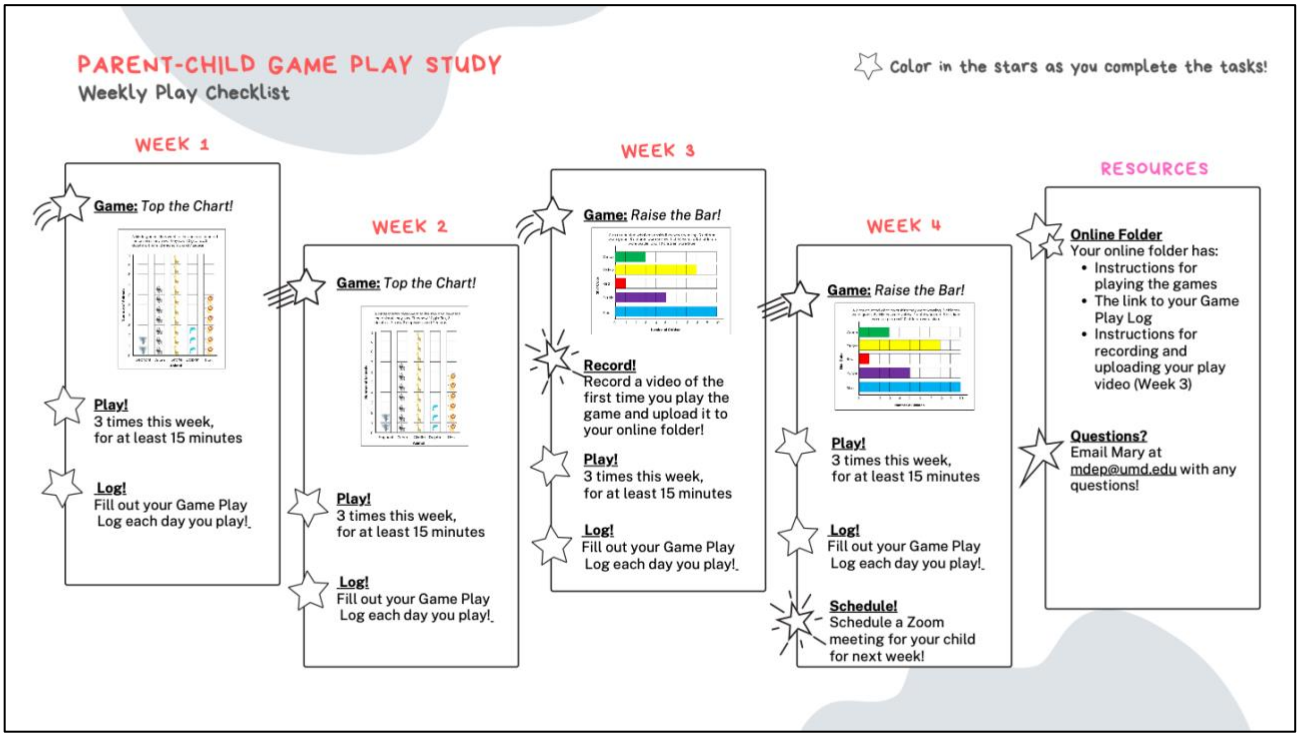


Figure 4. Example weekly play checklist. Participants received a paper copy with their game materials in addition to the copy in their online folder.

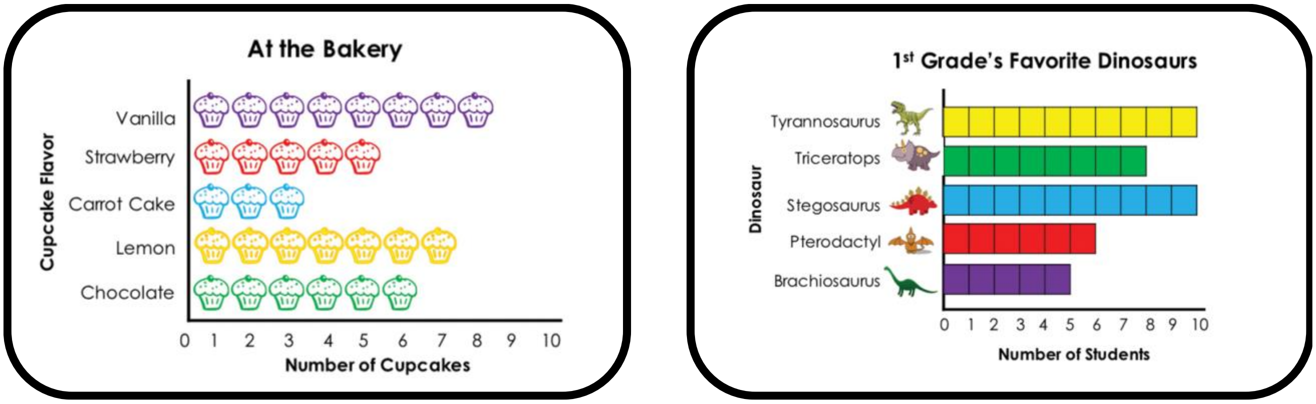


Figure 5. Example cards from graphing card games with picture graphs (left) and bar graphs (right).

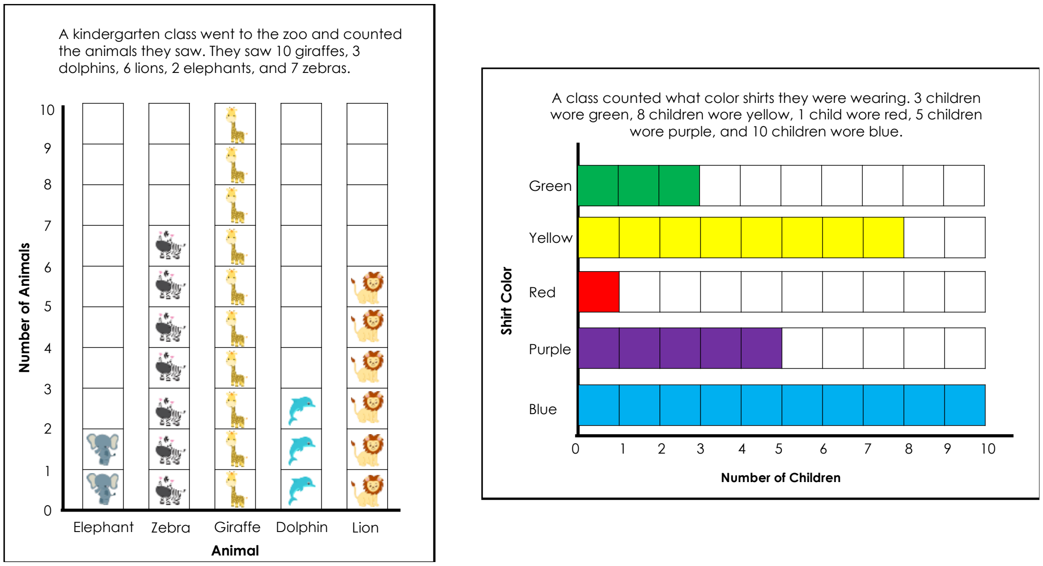


Figure 6. Picture graph (left) and bar graph (right) game boards for graphing board game. Players started with an empty board, and throughout the game collected tiles to fill in their boards, as depicted here.

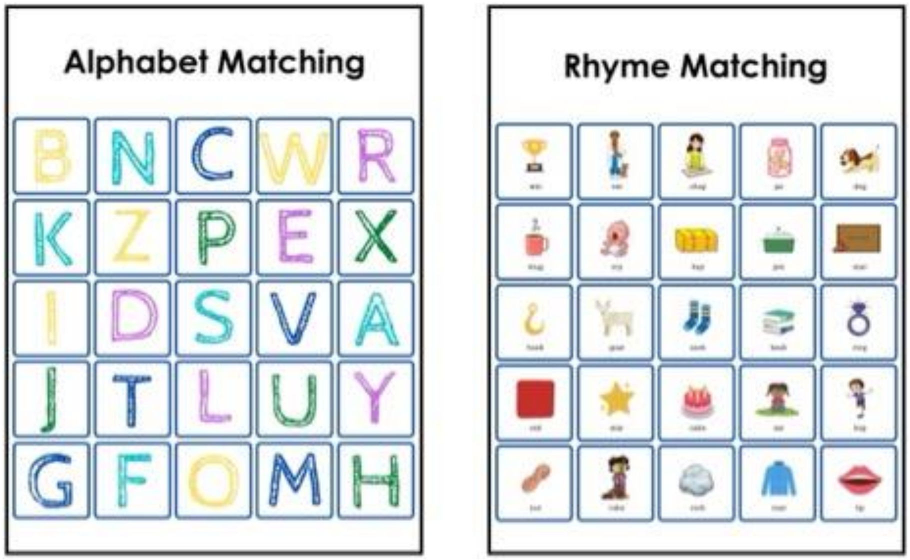


Figure 7. Game boards for alphabet matching (left) and rhyme matching (right) literacy board games. Players each started with an empty board as depicted, and throughout the game they collected cards to fill in their board.

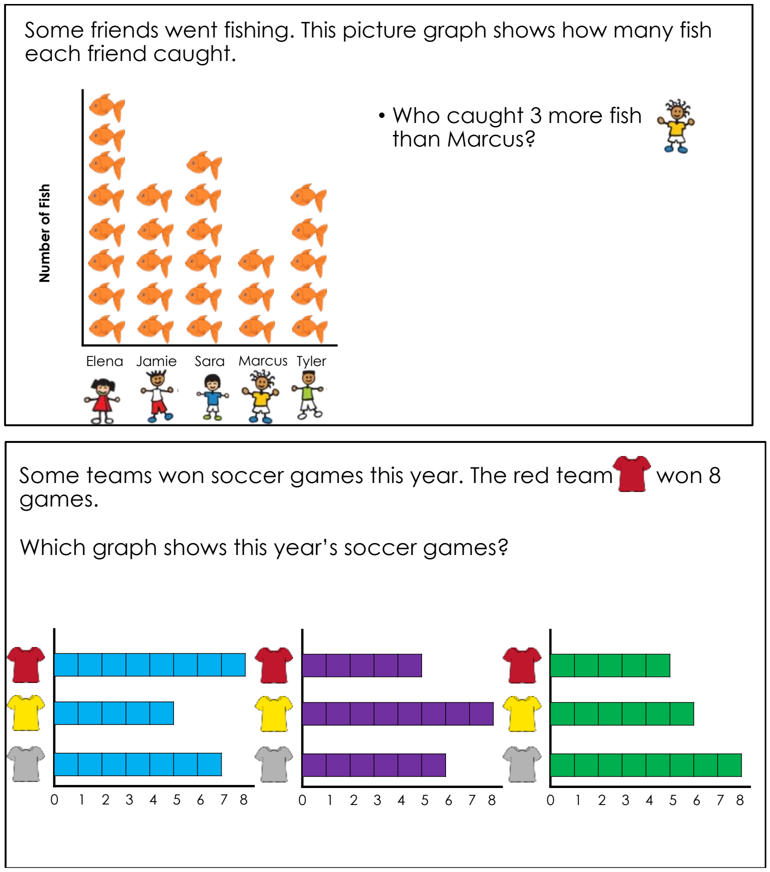


Figure 8. Sample items from the statistical understanding measure. A sample item for interpreting graphs is shown on the top, and a sample item for constructing graphs is shown on the bottom.

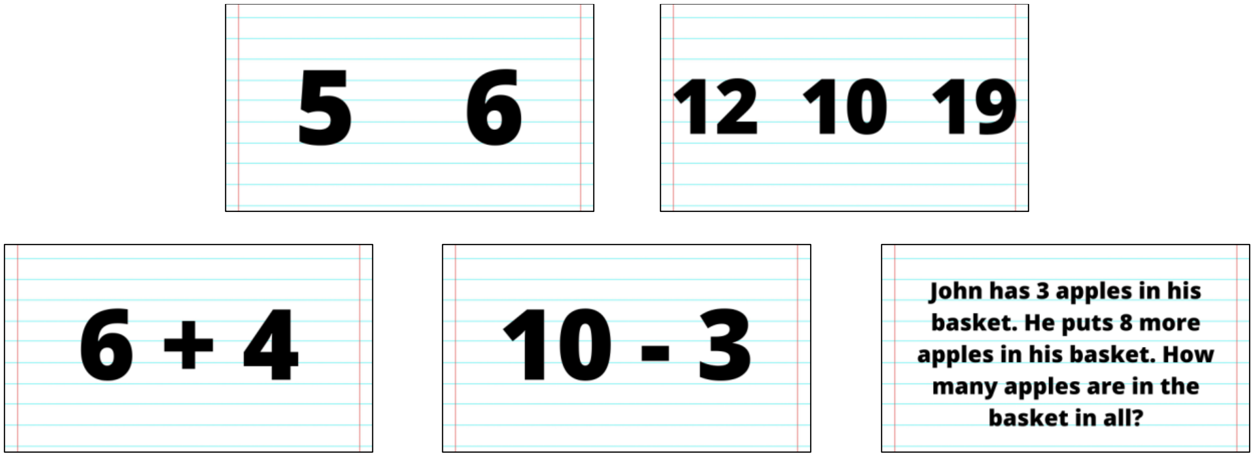
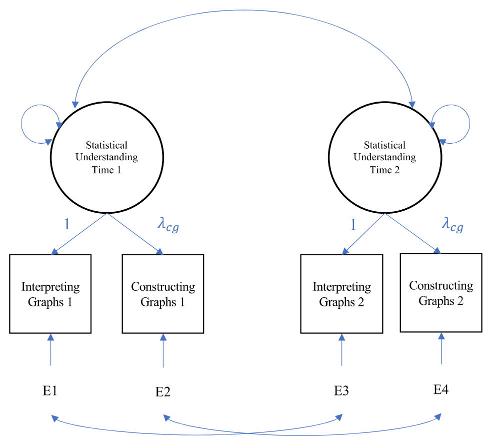
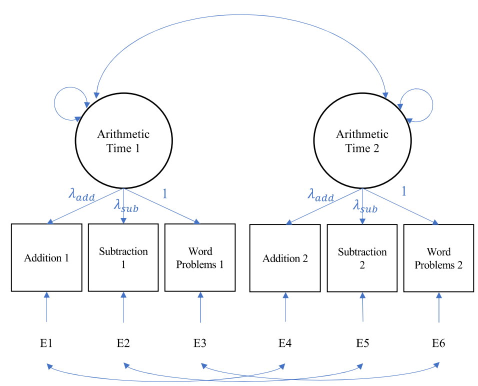


Figure 9. Sample items from the measures of math ability. Top: Sample magnitude comparison items, including a pair (left) and set of three numbers (right). Bottom: Sample arithmetic items, including addition (left), subtraction (center), and word (right) problems.

Statistical Understanding



Arithmetic



Magnitude Comparison

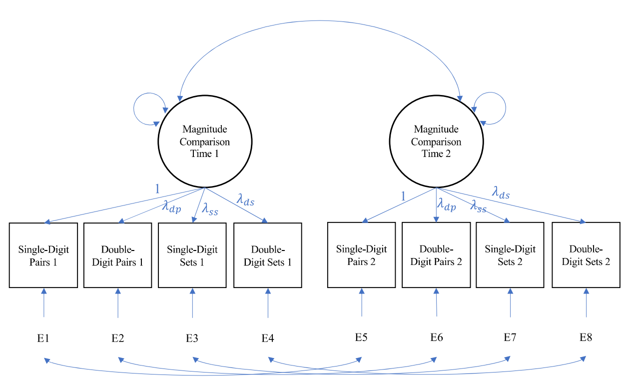
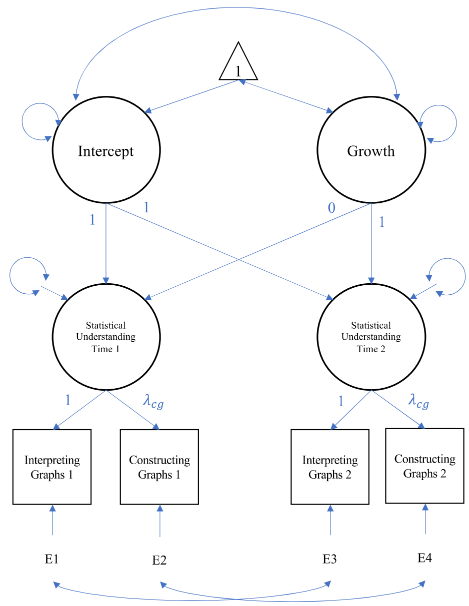


Figure 10. Measurement models for Statistical Understanding, Arithmetic, and Magnitude Comparison. Models were identical for each condition.

Statistical Understanding



Arithmetic

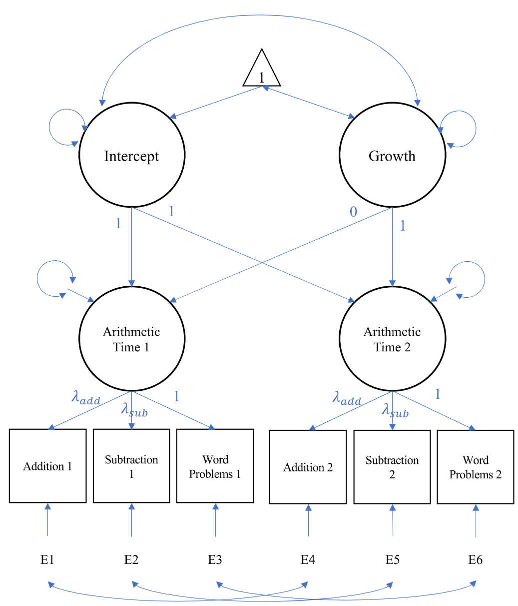


Figure 11. Multigroup growth models used to examine Aim 1a. Models were identical for each condition.

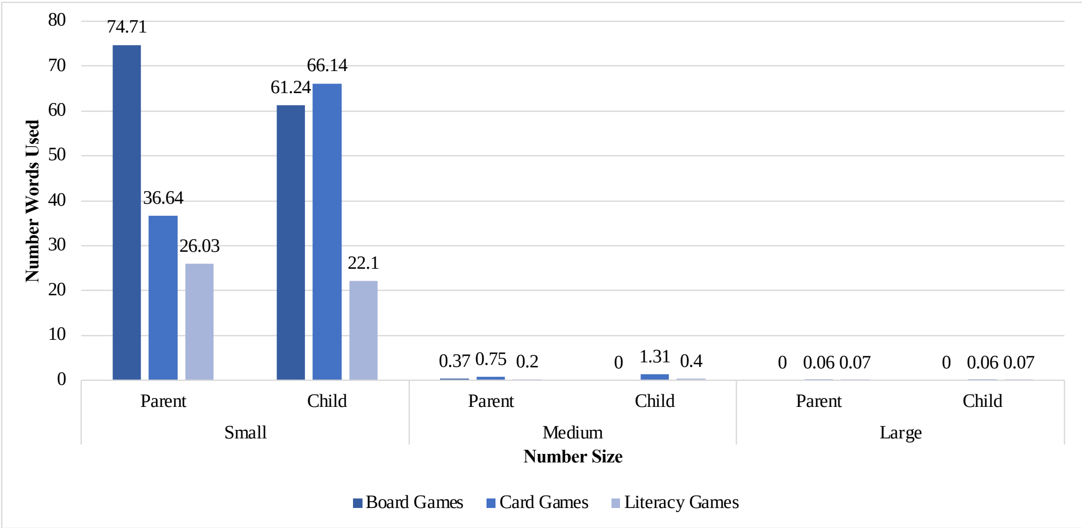


Figure 12. Parent and child average use of small, medium, and large number words, by condition.

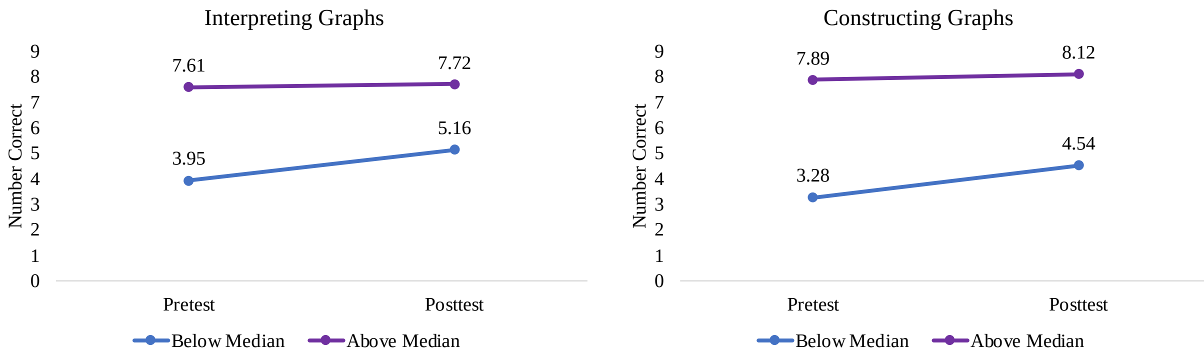


Figure 13. Average scores at pretest and posttest for participants below and above the median pretest statistical understanding score

Appendices

Appendix A: Parent Demographic Questionnaire

Please tell us a little about you and your child. The information will be kept confidential and will not influence you and your child's eligibility to participate in the study.

1. What is your child's age?
   - ○ 5 years old
   - ○ 6 years old

2. What is your child's date of birth (mm/dd/yyyy)? ______________________

3. What is your child's gender? ______________________

4. What is your child's race?
   - ❑ African American or Black
   - ❑ Caucasian/White
   - ❑ Asian or Pacific Islander
   - ❑ American Indian or Alaska Native
   - ❑ Biracial/Mixed Race (Please list all groups that apply) ____________________________

5. Is your child Hispanic or Latino?
   - ○ Yes
   - ○ No

6. What is your race?
   - ❑ African American or Black
   - ❑ Caucasian/White
   - ❑ Asian or Pacific Islander
   - ❑ American Indian or Alaska Native
   - ❑ Biracial/Mixed Race (Please list all groups that apply) ____________________________

7. Are you Hispanic or Latino?
   - ○ Yes
   - ○ No

8. Language(s) spoken at home (Select all that apply):
   - ❑ English
   - ❑ Spanish
   - ❑ French
   - ❑ Chinese

- ❑ Other (please specify) ____

9. Please indicate the highest level of education completed by each of the child's parents:

Parent 1:

- ❑ Some High School
- ❑ High School Diploma/GED
- ❑ Some College Coursework/Vocational Training
- ❑ 2-year College Degree (Associates)
- ❑ 4-year College Degree (BA/BS)
- ❑ Postgraduate or Professional degree (MA, PhD, MD, JD)

Parent 1's relationship to child: ___________

Parent 2:

- ❑ Some High School
- ❑ High School Diploma/GED
- ❑ Some College Coursework/Vocational Training
- ❑ 2-year College Degree (Associates)
- ❑ 4-year College Degree (BA/BS)
- ❑ Postgraduate or Professional degree (MA, PhD, MD, JD)

Parent 2's relationship to child: ___________

10. The zip code in which your child lives: ____________________________

11. Please indicate your annual household income:

- ❑ Less than $15,000
- ❑ $15,000 - $30,000
- ❑ $31,000 - $45,000
- ❑ $46,000 - $59,000
- ❑ $60,000 - $75,000
- ❑ $76,000 - $100,000
- ❑ $101,000 - $150,000
- ❑ $151,000 or more

12. During the week, does your child attend the following? Please indicate the number of hours per week of attendance at each of the following:

- ❑ PreKindergarten (___ hours/week)
- ❑ Kindergarten (___ hours/week)
- ❑ 1st grade (___ hours/week)
- ❑ Other_______________ (___ hours/week)

13. Does your child currently attend the following?

- ❑ Public school

- ❑ Charter school
- ❑ Private school
- ❑ Other (please specify)

____

14. Please indicate how your child has been attending school:
    - ❑ In person
    - ❑ Virtually / online
    - ❑ Hybrid (in person and online)
    - ❑ Other (please specify)

    ____

Appendix B: Sample Task Scripts

Statistical Understanding Task

For this first game, I'm going to ask you some questions about graphs. First I'll show you a graph, then I'll ask questions about it.

[Show slide and read each question] Example question: **Some friends went fishing. This picture graph shows how many fish each friend caught. Who caught 3 more fish than Marcus?**

Appropriate experimenter responses: **Alright! / Okay!**

Arithmetic Task

For the next game, I'm going to ask you to solve some number problems. Try to solve them as quickly as you can without making too many mistakes. You can use whatever way is easiest for you to get the answer, just don't write anything down.

[For each problem, show slide with problem on it] Example question: **What is 6 + 4?**

Appropriate experimenter responses: **Alright! / Okay!**

Magnitude Comparison Task

Now I have one more game for us to play. For this game, I'm going to show you numbers and ask you to tell me which is *more*. Try to answer as quickly as you can without making too many mistakes. Are you ready?

[Show slide with numbers, use cursor to point to each number as you read the question] Example question: **Which is more, 4** [point to 4 with cursor] **or 7** [point to 7 with cursor]**?**

Appropriate experimenter responses: **Alright! / Okay!**

Appendix C: IRB Approval Letter

UNIVERSITY OF MARYLAND

DATE:	February 17, 2021
TO:	Geetha Ramani
FROM:	University of Maryland College Park (UMCP) IRB
PROJECT TITLE:	[1648945-2] Parent-Child Game Play
REFERENCE #:	
SUBMISSION TYPE:	Amendment/Modification
ACTION:	APPROVED
APPROVAL DATE:	February 17, 2021
EXPIRATION DATE:	September 2, 2021
REVIEW TYPE:	Expedited Review
REVIEW CATEGORY:	Expedited review category # 5 and 7. Subpart D applies, 45CFR46.404.

Thank you for your submission of Amendment/Modification materials for this project. The University of Maryland College Park (UMCP) IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

Prior to submission to the IRB Office, this project received scientific review from the departmental IRB Liaison.

This submission has received Expedited Review based on the applicable federal regulations.

This project has been determined to be a MINIMAL RISK project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of September 2, 2021.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Unless a consent waiver or alteration has been approved, Federal regulations require that each participant receives a copy of the consent document.

Please note that any revision to previously approved materials must be approved by this committee prior to initiation. Please use the appropriate revision forms for this procedure.

All UNANTICIPATED PROBLEMS involving risks to subjects or others (UPIRSOs) and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this office.

Please note that all research records must be retained for a minimum of seven years after the completion of the project.

If you have any questions, please contact the IRB Office at 301-405-4212 or irb@umd.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within University of Maryland College Park (UMCP) IRB's records.

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