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The Role of Math Games for Children's Early Math Learning: A Systematic Review

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Abstract

Math learning in early childhood is critical for later success, as it is predictive of mathematical and academic achievement through adolescence. Therefore, developing engaging and effective methods for early math instruction are important. Math games are a common method for teaching math in a way that is motivating and engaging for young children and are often used in early childhood classrooms. However, research on what games are effective and who can benefit from playing them often focuses on single elements or contexts of gameplay, and there is little research summarizing the effects of math games on children's learning. The current systematic review presents research on the impact of math games on preschool through third grade children's math development, examining what game contexts, types, and content areas are effective for math learning, who can learn from games, and what features of math games effectively promote learning in early childhood. Themes in the literature include the impact of game design factors, math outcomes studied, and dosage of gameplay for learning through games. The review reveals that future research is needed to compare the effects of gameplay across contexts and to examine additional factors influencing children's learning from games.

Keywords

math games, math gameplay, early childhood, early math, numeracy, home math environment

Non-Technical Summary

Background

Developing a strong foundation in math skills in early childhood is important for children's learning and development. To support children's early math learning, it is critical to have methods for teaching and learning math that are engaging and effective for children. Games and play provide opportunities for children to develop and practice math skills in a way that is engaging, active, and meaningful to them.

Why was this study done?

Previous research studies on what math games are effective for children's learning and who can benefit from playing math games have primarily focused on individual elements or contexts of play, and there has been less work done to summarize the effects of math games on children's math learning in early childhood.

What did we do and find?
We conducted a systematic review of studies (from 2000 – 2024) of math games and children's math learning. We specifically considered what game contexts, types, and content areas are effective for math learning, who can learn from games, and what features of math games effectively promote learning in early childhood. Overall, we found that math games played at home and school (with parents, peers, teachers, experimenters, and others) support children's early math learning. We also found that different elements of games can be designed to support and promote math learning and engagement.

What do these findings mean?
Our findings show that math games can promote math learning in early childhood and emphasize the importance of considering game design factors, dosage of gameplay, and math outcomes when considering the role of math games for children's math learning and engagement.

Highlights

- We conducted a systematic review of math games in early childhood.
- Studies included numerical board games, card games, and physical/sets of games.
- Children learn from math gameplay with parents, peers, teachers, and experimenters.
- Elements of math games can be designed to facilitate more meaningful engagement.
- Themes include game design factors, dosage of play, and math outcome measures.

A strong foundation in math is essential for 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). Because early math is critical for later success, developing engaging and effective methods for early math instruction is important.

As games and play can provide an engaging context for early learning (Golinkoff et al., 2006), games focused on math content are a recommended method for teaching early math concepts. In line with this, many games have been developed (commercially and by researchers) for children to play in early educational contexts (e.g., home and school settings) to promote children's mathematical abilities. Despite this, research on what games are effective and who can benefit from playing them often focuses on single elements or contexts of gameplay, and there is little research evaluating and summarizing the effects of math games for children's learning.

The aim of this systematic review is to present the research to date on the impact of math games on early childhood math development, specifically examining what game contexts, types, and content areas are effective for math learning, who can learn from math games, and what features of math games promote learning. Understanding the nuances of the benefits of math games is critical so that games can be used effectively with children, and recognizing the features that make games effective is essential for game design. We first provide a theoretical background for the use of play and games in learning. We then present the aims, search strategy, and results. Finally, we discuss overall themes and future research directions.

Theoretical Background

Developmental theories support the use of play and games to promote children's learning. Sociocultural theory highlights the importance of adult scaffolding of children's learning (Vygotsky, 1986). In math games, adult scaffolding can include guiding children to a new learning outcome through elements of the game (e.g., providing a counting strategy for moving spaces on the board). Importantly, studies show that parents and teachers can determine children's abilities and appropriately adapt guidance in gameplay contexts (Bjorklund et al., 2004; Ramani et al., 2012; Rogoff et al., 1984).

Cognitive developmental theories also highlight the importance of children's active engagement in their learning (Piaget, 1950). Games constitute a context of active engagement, as gameplay allows children to directly practice and explore concepts in a structured, dynamic way. Further, children can acquire new knowledge and skills through discussions and play with their peers (Piaget, 1950). Games can promote learning in this way as they facilitate children's engagement in a learning activity with peers or other players.

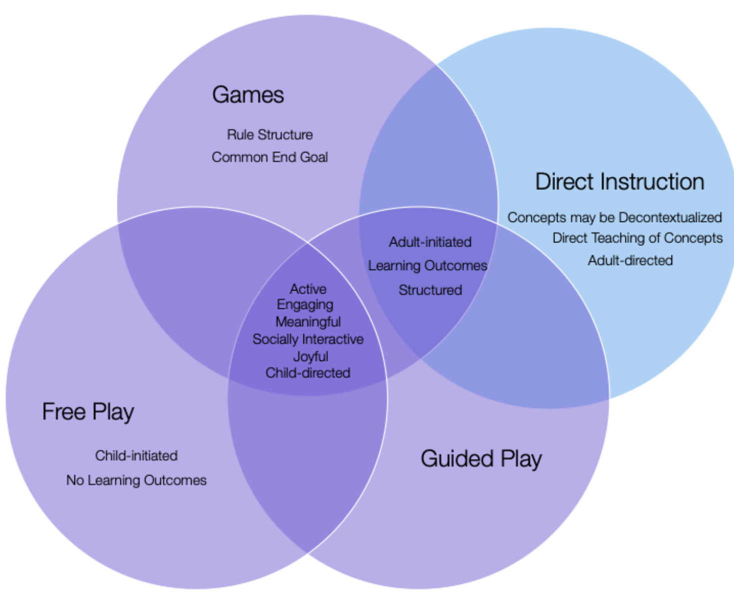
Games and Playful Learning

In addition to classic developmental theories, more recent work also describes play and games as important for promoting early social, emotional, and cognitive skills (Golinkoff et al., 2006). In early math, play is particularly important because it incorporates math concepts into everyday experiences in a way that builds on children's math interests. When engaging in play, children naturally explore mathematical topics by counting, sorting, and making categories, patterns, and comparisons (Ginsburg, 2006; Sarama & Clements, 2009). This self-initiated exploration of math-related topics 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 support children's math interests and skills.

Playful learning theories consider types of learning opportunities for young children, including free play, guided play, and games (Hassinger-Das et al., 2017). The characteristics and definitions of playful learning are summarized in Figure 1. In addition, the theories highlight six components of playful learning opportunities which can promote early learning and development—being active, engaging, meaningful, socially interactive, joyful, and iterative (Zosh et al., 2018). Table 1 provides an overview of how math games can promote early learning through each of the components of playful learning, including connections to developmental theories and empirical support, which is further detailed in the following sections.

Figure 1

Summary of Definitions of Playful Learning and Direct Instruction



Note. Summary of definitions of games, play, and direct instruction. Playful learning methods (i.e., free play, guided play, games) are shown in purple and non-playful learning methods (i.e., direct instruction) are shown in blue. For detailed discussions of playful learning see Hassinger-Das et al. (2017) and Zosh et al. (2018).

While play and games both contribute to children's learning, it is important to distinguish what constitutes a game. Games are a type of *playful learning*, and they include all the elements of play in that they allow for child agency, are engaging, and support learning in an active, structured way (Hassinger-Das et al., 2017). What separates games from play is that they include concrete, directed goals and a formal rule structure (Figure 1; Hassinger-Das et al., 2017; Rubin et al., 1983). To play a game, players must have the same end goal in mind and follow the same 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 (e.g., repeated practice of skills) and aspects of the social interactions involved in gameplay (e.g., guidance or feedback from other players).

Table 1

Summary of How Math Games Can Promote Early Learning Through a Playful Learning Perspective

Playful Learning Component	Math Games	Theoretical and Empirical Support
Active	• Context for active engagement, which allows children to: ◦ Actively construct math knowledge through the processes of playing the game ◦ Directly practice and explore math concepts in a structured, dynamic way	Clements & Sarama (2014); Piaget (1950); Sarama & Clements (2009)
Socially Interactive	• Context for interactions with peers and adults, including: ◦ Scaffolded interactions to support math concepts (e.g., counting strategies for moving on a game board; prompts for math skills) ◦ Discussions and interactions with peers to support and promote math knowledge (e.g., feedback on problem solving)	Bjorklund et al. (2004); Piaget (1950); Ramani et al. (2012); Rogoff et al. (1984); Vygotsky (1986)
Engaging	• Engaging and motivating setting for early math learning • Players are engaged and focused on the game procedures and play	Clements & Sarama (2014); Piaget (1950)
Meaningful	• Meaningful math learning opportunities, including those that: ◦ Build on children's natural math interests (e.g., counting, sorting, and making categories, patterns, and comparisons) ◦ Allow for engaging with math concepts in a contextualized way (e.g., game themes and contexts; applications of math skills in the game)	Clements & Sarama (2014); Ginsburg (2006); Sarama & Clements (2009)
Joyful	• Fun and enjoyable context for early learning	Fisher et al. (2012); Golinkoff et al. (2006)
Iterative	• Repeated practice with math skills through the processes of playing the game (e.g., counting on from spaces on the game board; comparing quantities to advance in the game)	Fisher et al. (2012); Hassinger-Das et al. (2017)

In addition, playful learning theories contrast playful learning methods (i.e., free play, guided play, games) with direct instruction—a teaching method where learning is adult-directed and concepts are directly taught (Hassinger-Das et al., 2017; Zosh et al., 2018). The theories posit that play, games, and direct instruction are all valid instructional methods, 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, playful methods may be more engaging for students, as play and games are interactive and fun (Ilgaz et al., 2018).

Further, games can provide a setting for math learning that situates math concepts in a context. In contrast, direct instruction may decontextualize concepts, which is less engaging and motivating for students. In this way, games can complement concepts taught via direct instruction, to further contextualize and motivate students (Clements & Sarama, 2014; Sarama & Clements, 2009) and to practice engaging in mathematical thinking and problem solving (Fisher et al., 2012).

The importance of games and play for early math learning is supported by research on the home math environment (HME). HME measures often include math games as an informal opportunity to engage in math, and HME studies have found that playing math games at home relates to children's math skills concurrently (e.g., Benavides-Varela et al., 2016; LeFevre et al., 2009) and longitudinally (e.g., Zhang et al., 2020).

Beyond the HME, incorporating games into learning at school can support math development. Math curricula including game-based instruction can improve preschool and elementary school math learning (Clements & Sarama, 2007; Wendt et al., 2014). Additional work has also identified games and play-based learning as instructional methods that align with standards such as the Common Core State Standards Mathematics Standards for all elementary school grades (Zosh et al., 2016).

Prior Systematic Reviews and Meta-Analyses

In early math, systematic reviews and meta-analyses have examined family math engagement (Eason et al., 2022) and relations between the HME and early math abilities (Daucourt et al., 2021; Mutaf Yıldız et al., 2020). Additional meta-analyses have examined the effectiveness of math interventions and programs. Specifically, two meta-analyses have examined numeracy interventions (e.g., books, activities, programs, digital apps; Nelson & McMaster, 2019; Nelson et al., 2024), and two have examined interventions (e.g., curricula, professional development, programs, activities) for math in the PreK-K and K-12 age ranges (Wang et al., 2016; Williams et al., 2022). These studies included some game interventions; however, these were either limited in the number of studies of games represented (and did not include *game* as a search term; Nelson et al., 2024; Nelson & McMaster, 2019; Wang et al., 2016) or only included digital games (Williams et al., 2022).

Few reviews have specifically examined games and math. Dondio et al. (2023) conducted a meta-analysis that examined the role of games in reducing math anxiety. Their review included games (broadly, not specifically math games) played by children ages 7-12 and college students, and the majority of studies were digital games. Balladares et al. (2024) examined the role of playing board games in education settings for children's math and non-math outcomes. The review included math and non-math board games, focused only on PreK-K, and only focused on effects on math outcomes (i.e., did not include moderator analyses).

While these reviews provide insight into certain effects of gameplay for math, math anxiety, and other outcomes, more work is needed to specifically examine the effects of math games, including the role of context and features that promote learning. The current review fills this gap in the literature by examining the context, type, and content of math-specific games, and the features of games that are effective in promoting early learning. Understanding what makes math games effective is important as it allows for further evidence-based design and use of math games to enhance children's learning.

Current Review

Our review has three aims. The first aim was to understand what game contexts, types, and content areas are effective for children's math learning. It is possible that certain contexts of play lend themselves to different influences on math learning. For example, contexts (e.g., home, school; playing with an experimenter, parents, teachers, peers) may differ in the extent to which they incorporate active, scaffolded social interactions and other components of playful learning into gameplay. It is also possible that the type and content of the game may impact children's learning. For example, card games, board games, and physically active games all vary in their design and materials, and these variations may lead to differences in children's learning.

The second aim was to understand if playing math games is beneficial for all children's math learning in the same way. It is important to understand if the benefits of math games are equal or if certain group differences may impact children's learning from math games, as this can inform the design of game interventions to improve learning. We considered research that included any measurable group differences (e.g., age, SES, cognitive factors) as possible points for divergent impacts of math gameplay.

The third aim was to examine what features of math games effectively promote children's math learning. There is a general understanding that playing games can promote math learning. However, it is critical to understand what features of math games specifically make them effective. This could be addressed in the existing research with studies that (1) directly compare which format, designs, or procedures produce greater gains in learning or (2) consider how different types of interactions during play relate to learning. Because games are inherently social, understanding what types of interactions promote learning is important for designing games to facilitate productive math interactions.

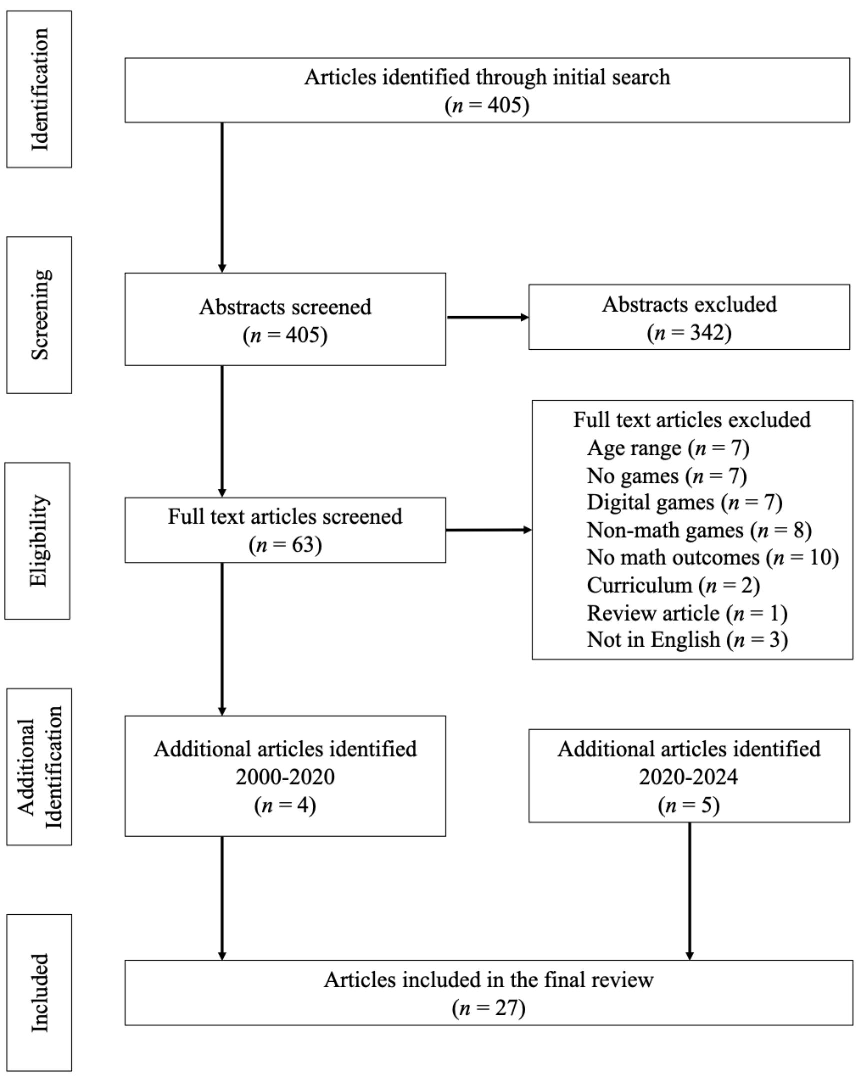
Method

Search Strategy

The APA PsycINFO database was searched in February 2020. Search terms included *math** and *games* or *gameplay*, limited to preschool and school ages[1]. Results for peer-reviewed journal articles in the last 20 years (2000-2020) resulted in 405 articles. Article titles and abstracts were reviewed according to inclusion criteria (described below). After screening, 63 articles remained for full-text review and 18 of these articles were retained after review. Citations lists of the 18 included articles were reviewed by title. Five additional articles were identified, with 4 meeting the inclusion criteria[2]. We also identified 5 articles published after the initial search (i.e., 02/2020–06/2024) which met the inclusion criteria. In total, 27 articles were used in the final review (Figure 2).

Figure 2

Summary of Search Strategy



1) The search strategy and search terms were developed with feedback from a university librarian.

2) Review of the citations of these 4 articles resulted in a subset of articles already included in the review.

Reliability

Two researchers were involved in screening. One researcher screened all 405 articles and a second researcher double-screened 10% of the articles. Percent agreement was 93%. The three abstracts that received different screening decisions were retained and evaluated during full text review. One researcher conducted full text screening, in discussion with a second researcher for any cases where it was unclear if inclusion criteria were met (e.g., determining math games versus math tasks).

Inclusion Criteria

To be included, articles had to be peer-reviewed and written in English in the last twenty years (2000-2020). We chose to include only published, peer-reviewed studies as there may be differences in the quality of non-peer-reviewed studies (e.g., methodological concerns). Further, studies have shown that the inclusion of unpublished studies does not always reduce publication bias and also has the potential to increase other selection biases (e.g., including a biased sample of the unpublished work, such as work primarily done by the primary authors' colleagues) (Ferguson & Brannick, 2012, as cited in Schneider et al., 2018). In line with this, including only peer-reviewed literature is also consistent with prior systematic reviews and meta-analyses published in the field (e.g., Eason et al., 2022; Schneider et al., 2017, 2018; Wen & Dubé, 2022).

Articles also had to include an early childhood sample (preschool-grade 3; 3-9 years); a typically-developing sample; a traditional (non-digital) game; a math game, and math outcome measures. Studies focusing solely on behaviors or interactions during gameplay (with no measured math outcomes) were not included, as they did not provide information on the role of games in math learning. Studies including games administered as part of a larger curriculum or intervention were also not included, as it is not possible to distinguish the effect of games on children's outcomes from the effects of other intervention elements (e.g., books, learning activities).

Only studies examining traditional (non-digital) games were included. There is more variability in the context of digital gameplay, as children may be more likely to play these games individually, versus playing with others. 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 (Zosh et al., 2015). While digital games can be designed to provide feedback to children (Ramani et al., 2020), this is not equivalent to an adult providing prompts targeted specifically to that child's ability level. Because of these differences, digital games did not fit into the aims of the current review.

For the purposes of this review, 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 to children as a game—possibly to increase engagement—tasks were not considered games unless they fit into the playful learning framework described above.

Results

To address the aims of the review, information extracted from the articles included: children's age, game type, content, description, context, and dosage, math outcome measures, and results including any reported group differences or elements identified as effective for learning. To ensure valid and reliable extraction, the information extracted was checked by a second researcher for 30% of the articles.

Of the 27 articles reviewed, 23 were experimental and four were correlational studies. The majority of studies were intervention studies, focused on preschoolers, and included games played at school (see Table 2). Because aim 1 encompassed the context and content of gameplay, all of the articles (*n* = 27) were considered relevant. Results for aim 2 included five articles, and results for aim 3 included 18 articles. Articles containing more than one pertinent study were considered as one article unless otherwise noted.

Table 2

Summary of Participant Age and Game Characteristics

Study	Age (Grade)	Game Type	Game Content	Game Context	Study Type
Casey et al. (2020)	1st Grade	Card Game	Advanced	Home	Intervention
Chao et al. (2000)	Kindergarten	Set of Games	Advanced	School	Intervention
Cheung & McBride-Chang (2015)	Preschool	Card Game	Advanced	Home	Intervention
Cheung & McBride (2017)	Kindergarten	Board Game	Advanced	Home	Intervention
de Chambrier et al. (2021)	Kindergarten	Set of Games	Advanced	School, Home	Intervention
Elofsson et al. (2016)	Preschool	Board Game	Advanced	School	Intervention
Guberman & Saxe (2000)	3rd-4th Grade	Board Game	Advanced	School	Intervention
Hurst et al. (2022)	1st-2nd Grade	Card Game	Advanced	School	Intervention
Jirout et al. (2018)	K-2nd Grade	Physical Game	Advanced	School	Single Time Point
Laski & Siegler (2014)	Kindergarten	Board Game	Advanced	School	Intervention
Loehr & Rittle-Johnson (2017)	3rd-4th Grade	Card Game	Advanced	School	Single Time Point
Navarrete et al. (2018)	Preschool	Physical Game	Basic	School	Intervention
Ramani & Scalise (2020)	Preschool	Card Game	Advanced	Home	Intervention
Ramani & Siegler (2008)	Preschool	Board Game	Basic	School	Intervention
Ramani & Siegler (2011)	Preschool	Board Game	Basic	School	Intervention
Ramani et al. (2012)	Preschool	Board Game	Basic	School	Intervention
Ribner et al. (2023)	Preschool	Board Game	Advanced	Home	Intervention
Scalise et al. (2018)	Preschool	Card Game	Advanced	School	Intervention
Siegler & Ramani (2008)	Preschool	Board Game	Basic	School	Intervention
Siegler & Ramani (2009)	Preschool	Board Game	Basic	School	Intervention
Silver et al. (2024)	Preschool	Board Game	Advanced	Home	Intervention
Skillen et al. (2018)	Kindergarten	Board Game	Advanced	School	Intervention
Sonnenschein et al. (2016)	Preschool	Board Game	Advanced	Home	Intervention
Van Herwegen et al. (2017)	Preschool	Set of Games	Advanced	School	Intervention
Vandermaas-Peeler & Pittard (2014)	Preschool	Board Game	Basic	Home	Single Time Point
Vandermaas-Peeler et al. (2012)	Preschool	Board Game	Basic	Home	Intervention
Whyte & Bull (2008)	Preschool	Board Game, Card Game	Advanced	School	Intervention

What Game Contexts, Types, and Content Areas Are Effective?

The first aim was to examine what game contexts, types, and content areas are effective for children's math learning, including physical and social contexts of gameplay. Games were classified into three categories: board games (n = 16), card games (n = 7), and physical/sets of games (n = 5). Games were further classified by math content: basic (e.g., numbers under ten) or advanced (e.g., numbers greater than ten, base ten, magnitude comparison, arithmetic, fractions, decimals, spatial reasoning), consistent with definitions of basic and advanced math content used in other studies (e.g., Powell & Nurnberger-Haag, 2015; Ramani et al., 2015). Table 2 provides a summary of the game type, content, and context for each study.

Context of Gameplay

Context was defined by the location of play (e.g., home, school) and the social partners engaged in play (e.g., parents, peers, teachers, experimenters). One study examined the social context of play. Specifically, Guberman and Saxe (2000) considered the age of children's peer co-players. In examining children's arithmetic strategy use, they found that third graders who played with same-age peers used simpler strategies, while third graders who played with older peers used more sophisticated strategies. This suggests that children may benefit more from playing with older children, and highlights a social aspect of gameplay, in that children's play behaviors and learning depend on the abilities, behaviors, and learning of other players.

Nine studies examined games played at home with parents. Twenty-one studies examined games played at school with experimenters (*n* = 14) or teachers, paraprofessionals, peers, or parents (*n* = 7). One study included conditions where children played games at school or both at school and at home (de Chambrier et al., 2021). However, no articles specifically experimentally examined the effect of location of gameplay for math learning. Thus, no inferences can be drawn about the specific role of the physical 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 are elaborated in Tables 3 and 4 and Figure 3. Findings also indicated that non-researchers (parents, teachers, paraprofessionals) are capable of administering researcher-developed games in a way that is engaging and meaningful for children. This is important, as the benefits of math games are less meaningful if they cannot be translated into real-world, applied settings such as homes and classrooms.

Game Type and Content: Board Games

Basic Number Skills — Studies of basic numerical board games focused on two games— The Ladybug Game, a commercially-available game (Vandermaas-Peeler et al., 2012; Vandermaas-Peeler & Pittard, 2014) and The Great Race, a researcher-developed game (Ramani & Siegler, 2008, 2011; Ramani et al., 2012; Siegler & Ramani, 2008, 2009).

The Ladybug Game involves moving spaces along a path to help a ladybug get home. Both studies using The Ladybug Game found that parent guidance during gameplay related to children's scores on the Test of Early Mathematics Ability (TEMA; Ginsburg & Baroody, 2003).

The Great Race is a horizontal 0-10 linear board game. Studies compared playing the linear number version of the game to either a linear color version or circular number versions of the game. Across studies, children who played the linear number game improved more than children who played the color game (Ramani & Siegler, 2008; Ramani et al., 2012; Siegler & Ramani, 2008) and the circular number game (Ramani & Siegler, 2011; Siegler & Ramani, 2009). Further, for the comparison of the number and color games, findings indicated that results were consistent two months after gameplay (Ramani & Siegler, 2008) and when children played the number game in groups led by a paraprofessional (Ramani et al., 2012).

Advanced Number Skills — The majority of articles examining board games for children's advanced number skills fell into two categories—games that displayed numbers linearly versus circularly (*n* = 2) and 10x10 grid games (*n* = 3). Consistent with findings from board games for basic number skills, studies that examined linear and circular board games displaying numbers ranging from 1-30 or 1-40 found that playing linear games led to greater improvements in numerical magnitude skills than playing circular games (Elofsson et al., 2016; Whyte & Bull, 2008).

Three articles considered different types of 10x10 grid 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 100 first. Findings indicated that gameplay led to improvements in number and math skills (Laski & Siegler, 2014; Skillen et al., 2018; Sonnenschein et al., 2016). In addition, two of the studies found that playing the games with a count on (i.e., count up from the number of the current space) versus a count from one procedure led to greater improvements (Laski & Siegler, 2014; Skillen et al., 2018).

Table 3

Summary of Study Methodology and Key Findings

Study	Study Conditions	Game Description	Dosage: Weeks	Dosage: Sessions	Key Findings
Casey et al. (2020)	Math Game	Arithmetic and magnitude comparison game: A magnitude comparison card game, similar to the card game "War." Players used a commercially-available deck of cards with the face cards removed. Players each simultaneously flipped over three cards and determined whose set of cards had the higher sum.	24 weeks	N/A	Playing the game related to medium-effect-size improvements on an addition task. Mothers' use of math fact hints during play related to improvements in children's arithmetic, but mothers' guidance about specific problem-solving strategies did not.
Chao et al. (2000)	Math Game; Math Game	Number games: A set of games (e.g., board games, card games, physical games) targeting number, arithmetic, and numerical relations related to 5s and 10s.	5 weeks	25 sessions	Playing the games improved kindergarteners' performance on numerical Stroop, backwards number sequence, addition strategies, subtraction, and understanding of special number relations for numbers with fives and tens. The type of game materials (representing numbers with a focus on 5s and 10s (i.e., *structurally*) or in a *varied* representation which did not emphasize any structural components of numbers) 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 addition strategy use. Both types of materials led to improvements on numerical interference and backwards number sequences.
Cheung & McBride-Chang (2015)	Math Game; Non-Game	Number sense game: A card game with cards showing a set of animals on one side and numerals on the other side, including total animals and each type of animal (e.g., 7 animals, 6 monkeys, 1 giraffe). Cards included numbers 0-10 and 10-20.	10 weeks	30* sessions	Children improved on numeral identification of a subset of numbers 1-99, object counting of sets sizes 4-20, rote counting, identifying a missing number in a string of consecutive numbers, numerical magnitude comparison, and single-digit addition. Effects were large for all measures.
Cheung & McBride (2017)	Math Game; Math Game; Non-Game; Non-Game	Linear number game: A horizontal linear board game with 30 spaces with the numbers 1-30.	4 weeks	8* sessions	Playing the game led to increases in counting, numeral identification of two- and three-digit numbers, and addition for children who played with parents who had completed 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.
de Chambrier et al. (2021)	Math Game; Math Game; Non-Game	Number games: A set of games (e.g., card games, board games, other games) targeting counting, magnitude comparison, seriation, ordinality, and arithmetic.	8 weeks	32 sessions	Children who played the games improved more on a test of early math skills than children who did not play the games at all.
Elofsson et al. (2016)	Math Game; Math Game; Non-Game; Non-Game	Linear number game: A linear board game with 10 spaces. Circular number board game: A circular number board game with 10 spaces. Versions of each game included the numbers 1–10, 11–20, 21–30 and 31–40. Players roll a die (1 to 3) to determine how many spaces to move.	3 weeks	4 sessions	Linear games led to medium-effect-size increases in arithmetic and 0-10 number line estimation. Both games led to similar, non-significant improvements in counting. Children who played the circular game improved more on naming numbers (subset of numbers 1-99) than children in either control group.

Study	Study Conditions	Game Description	Dosage: Weeks	Dosage: Sessions	Key Findings
Guberman & Saxe (2000)	Math Game; Non-Game	Treasure Hunt: A map-based board game for base ten, place value understanding, and arithmetic skills. Base ten blocks (units of 1, 10, 100, and 1000) are used as doubloons which are collected in treasure chests (cards showing thousands, hundreds, tens, and ones place values). Players roll a die to determine where to move. Players use arithmetic to make purchases with doubloons throughout the game.	10 weeks	20 sessions	Third graders improved on arithmetic accuracy, and students who played with older students (fourth graders) also used more sophisticated arithmetic strategies. Children who spontaneously took on thematic roles (e.g., customer, storekeeper) in the game used more sophisticated problem-solving strategies at posttest than children who did not.
Hurst et al. (2022)	Math Game; Math Game; Math Game	Fraction comparison game: A magnitude comparison card game, similar to the card game "War." Cards showed fractions that were actively divided, pre-divided, or non-divided.	1 week	2 sessions	Children who played the game where fractions were actively divided (e.g., children saw the experimenter divide the rectangle on the card into five equal pieces and color in one piece to represent one-fifth) improved more than children who played the game where fractions were pre-divided (i.e., the rectangle on the card was pre-divided into five equal pieces, and children saw the experimenter color in one piece to represent one-fifth) or non-divided (e.g., children saw the experimenter divide the rectangle on the card into two non-equal pieces, and color in the one-fifth-sized piece to represent one-fifth) on a symbolic-to-nonsymbolic fraction mapping task.
Jirout et al. (2018)	Math Game	Spatial scaling game: A physical game which involves using a map to locate a star on a life-size grid search space.	~12 minutes	1 session	Spatial scaling related to children's 0-100 number line estimation.
Laski & Siegler (2014)	Math Game; Math Game	Race to Space: A 10x10 grid board game with numbers 0 to 100.	3 weeks	4 sessions	Playing with a count on versus a count from one procedure led to improvement in 0-100 number line estimation, numeral identification of numbers 0-100, and counting. Reported effect sizes were large for counting and moderate for all other measures.
Loehr & Rittle-Johnson (2017)	Math Game; Math Game; Math Game	Decimal comparison game: A magnitude comparison card game, similar to the card game "War." Cards showed decimals labeled with formal, informal, or no labels.	< 40 minutes	1 session	Students playing the game with formal decimal labels performed better on decimal comparisons and place value knowledge, and children who played the game with no labels performed better on 0-1 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.
Navarrete et al. (2018)	Math Game; Math Game; Other Game	Embodied number line game: A 1-10 life-size number line game. Children sit on the sides of two life-size 1-10 linear number line game boards. The instructor and children move the life-size game tokens along the boards.	8 weeks	6 sessions	Playing the game related to medium- to large-effect-size improvements in tasks involving the numbers 1-10. Children also improved at numerical magnitude comparisons with numbers 1-9, however these improvements were not different than those of children who did not participate in the math game intervention. Children playing with a spatially-aligned perspective improved more in number line estimation than children playing with a spatially-misaligned perspective. Alignment did not affect counting, numeral identification, or magnitude comparison.
Ramani & Scalise (2020)	Math Game; Other Game	Top It, Take It: A magnitude comparison card game, similar to the game "War." Each player had a deck of 20 cards with the numbers 1-10.	6 weeks	12* sessions	The amount of time children played the game related to increases in their magnitude comparison of numbers 1-9 and 0-10 number line estimation. Time spent playing the game did not relate to counting, numeral identification of numbers 1-10, and cardinality for sets ranging 1-10.

Study	Study Conditions	Game Description	Dosage: Weeks	Dosage: Sessions	Key Findings
Ramani & Siegler (2008)	Math Game; Other Game	The Great Race: *Number version*: Horizontal 0-10 linear board game. Players spin a spinner with the numerals 1 and 2 to see how many spaces to move. *Color version*: Horizontal linear board game with 10 spaces with colors but no numbers. Players spin a spinner with colors to determine which space to move to.	2 weeks	4 sessions	Children who played the number game improved more than children who played the color game on 0-10 number line estimation, numeral identification 1-10, verbal counting 1-10, and magnitude comparison of pairs of numbers 1-9. These benefits were stable for at least two months.
Ramani & Siegler (2011)	Math Game; Math Game; Non-Game	The Great Race: *Linear number version* (see above). *Circular number version*: Circular 0-10 board game with 10 spaces.	3 weeks	4 sessions	Both linear and circular games led to greater improvements in children's number line estimation and numeral identification than the control group. However, for number line estimation, children who played the linear game improved more than those who played the circular game.
Ramani et al. (2012)	Math Game; Other Game	The Great Race: *Number version* (see above). *Color version* (see above).	3-4 weeks	4 sessions	Results were consistent with Ramani and Siegler (2008) and Siegler and Ramani (2008) when children played the number game in groups led by a paraprofessional.
Ribner et al. (2023)	Math Game; Other Game; Non-Game; Non-Game; Non-Game	All Around the Playground (adapted for number): Researcher-adapted version of a commercially-available path board game. The board contains 64 spaces with the numbers 1-64. Players spin a spinner to determine how many spaces to move.	8 weeks	16* sessions	Children who played the number game improved more on the TEMA compared to children who played a shape game, and children whose parents completed a digital ANS training task or a non-math training task.
Scalise et al. (2018)	Math Game; Math Game	War: A 1-10 magnitude comparison card game. Players each have a deck of 20 cards. Players each flip over one card simultaneously and determine which card has the larger number. Memory: A 1-10 number matching game. Cards are arranged face down. Players flip over two cards at a time to see if the numbers match.	3 weeks	4 sessions	Playing the magnitude comparison (War) game led to improvements in preschooler's counting 1-10, numeral identification of numbers 1-10, and symbolic (numbers 1-9) and non-symbolic (quantities 4-15) magnitude comparison abilities. However, improvements were only greater than those from the 1-10 matching card game (Memory) for children's symbolic magnitude comparison skills.
Siegler & Ramani (2008)	Math Game; Other Game	The Great Race *Number version* (see above). *Color version* (see above).	2 weeks	4 sessions	Children who played the number game improved more than children who played the color game on 0-10 number line estimation.
Siegler & Ramani (2009)	Math Game; Math Game; Non-Game	The Great Race: *Linear number version* (see above). *Circular number version* (see above).	3 weeks	4 sessions	Both linear and circular games led to greater improvements in children's number line estimation and numeral identification than the control group. However, for number line estimation, children who played the linear game improved more than those who played the circular game.
Silver et al. (2024)	Math Game; Other Game; Non-Game	All Around the Playground (adapted for number): (see above).	8 weeks	16* sessions	Children with initially higher number knowledge on a Give-N task had higher posttest TEMA scores after the gameplay intervention than children with initially lower number knowledge.
Skillen et al. (2018)	Math Game; Math Game	100 House: A 10x10 grid board game with numbers 0 to 100. The board has an "elevator" column in the middle (between numbers ending in 5 and 6). Players who land on a number ending in 5 can move up a floor.	4 weeks	4 sessions	Playing the 100 House game related to improvements on a standardized math test. Improvements were greater for children who played the game with a count on (i.e., count up from the number of the current space) 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 more advanced math skills.
Sonnenschein et al. (2016) – Study 1	Math Game; Math Game; Other Game	Chutes and Ladders: A commercially-available 10x10 grid board game with numbers 1 to 100. Candy Land: A commercially-available path board game with colors.	5 weeks	15* sessions	Both games led to improvements in preschooler's counting and 1-10 numeral identification.

Study	Study Conditions	Game Description	Dosage: Weeks	Dosage: Sessions	Key Findings
Sonnenschein et al. (2016) – Study 2	Math Game; Math Game; Math Game; Non-Game	Chutes and Ladders (see above).	5 weeks	15* sessions	All conditions improved on numeral identification. For 0-10 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.
Van Herwegen et al. (2017)	Math Game; Non-Game	Preschool Number Learning Scheme (PLUS) Training Games: A set of eight games (e.g., quantity guessing, number comparison, action repetition games) targeting preschoolers' ANS ability.	5 weeks	25 sessions	Playing the games related to increases in children's ANS abilities with a large effect size.
Vandermaas-Peeler & Pittard (2014)	Math Game	The Ladybug Game: A commercially-available board game that involves moving spaces along a path to help a ladybug get home. Players draw cards with 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 numerals and a quantity of circles with aphid characters).	15 minutes	1 session	Parent guidance during gameplay related to children's scores on the Test of Early Mathematics Ability (TEMA; Ginsburg & Baroody, 2003). Specifically, parent-child social engagement (e.g., referencing shared game experiences, connecting through jokes or laughing), related to children's math scores.
Vandermaas-Peeler et al. (2012)	Math Game; Math Game	The Ladybug Game (see above).	2 weeks	3* sessions	Parent guidance during gameplay related to children's scores on the Test of Early Mathematics Ability (TEMA; Ginsburg & Baroody, 2003). Specifically, parent guidance about addition and subtraction related to children's math scores.
Whyte & Bull (2008)	Math Game; Math Game; Other Game	Linear number game: linear board game with 10 spaces. Versions of the game included the numbers 1–10, 10-20, 20-30, and 30-40. Linear color game: linear board game with 10 spaces containing 5 colors. Nonlinear number game: A magnitude comparison card game, similar to the card game "War." Cards showed pictures of a quantity of apples on one side and the number of apples on the other side. Versions of the game included the numbers 1-25, 1-50, 1-75, and 1-100.	4 weeks	4 sessions	Both number games led to improvements in counting objects up to 20, number naming and magnitude understanding with numbers 1-9, and 0-10 number line estimation. Improvements for number line estimation were greater for children who played the linear board game.

Note. For studies conducted in the home environment, * indicates that the number of sessions is based on what the article's authors recommended or targeted as a number of sessions, rather than an exact number of sessions completed by all participants (as families could complete more or fewer sessions).

Table 4

Summary of Math Outcome Measures Studied

Study	Game Context	Counting	Numeral Identification	Magnitude Comparison	Number Line Estimation	Arithmetic	Cardinality	Math Interest	Non-symbolic Number	Place Value/ Base Ten
Casey et al. (2020)	Home/Parents					X̲				
Chao et al. (2000)	School/Peers/Teacher-led	*	*	*		X̲, *			*	X
Cheung & McBride-Chang (2015)	Home/Parents	X̲	X̲	X̲		X				
Cheung & McBride (2017)	Home/Parents	X̲	X̲			X̲		X̲		
de Chambrier et al. (2021)	Home/Parents and School/ Peers/Teacher-led	*̲		*̲		*̲	*̲			
Elofsson et al. (2016)	School/Experimenter	X	X̲		X̲	X̲				
Guberman & Saxe (2000)	School/Peers					X̲				
Hurst et al. (2022)	School/Experimenter								X̲	
Jirout et al. (2018)	School/Experimenter				X̲					
Laski & Siegler (2014)	School/Experimenter	X̲	X̲		X̲					
Loehr & Rittle-Johnson (2017)	School/Experimenter		X	X̲	X̲					X̲
Navarrete et al. (2018)	School/Experimenter	X̲	X̲	X̲	X̲					
Ramani & Scalise (2020)	Home/Parents	X	X	X̲	X̲		X			
Ramani & Siegler (2008)	School/Experimenter	X̲	X̲	X̲	X̲					
Ramani & Siegler (2011)	School/Experimenter	X	X̲	X̲	X̲	X̲				
Ramani et al. (2012)	School/Peers/ Paraprofessional-led	X̲	X̲	X̲	X̲					
Ribner et al. (2023)	Home/Parents	*̲	*̲	*̲		*̲			*̲	
Scalise et al. (2018)	School/Experimenter	X̲	X̲	X̲					X̲	
Siegler & Ramani (2008)	School/Experimenter				X̲					
Siegler & Ramani (2009)	School/Experimenter	X	X̲	X̲	X̲	X̲				
Silver et al. (2024)	Home/Parents	*̲	*̲	*̲		*̲			*̲	
Skillen et al. (2018)	School/Experimenter	*̲	*̲	*̲						
Sonnenschein et al. (2016)	Home/Parents	X̲	X̲	X	X̲					
Van Herwegen, et al. (2017)	School/Experimenter								X̲	
Vandermaas-Peeler & Pittard (2014)	Home/Parents	*̲	*̲	*̲		*̲			*̲	
Vandermaas-Peeler et al. (2012)	Home/Parents	*̲	*̲	*̲		*̲			*̲	
Whyte & Bull (2008)	School/Peers	X̲	X̲	X̲	X̲					

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.

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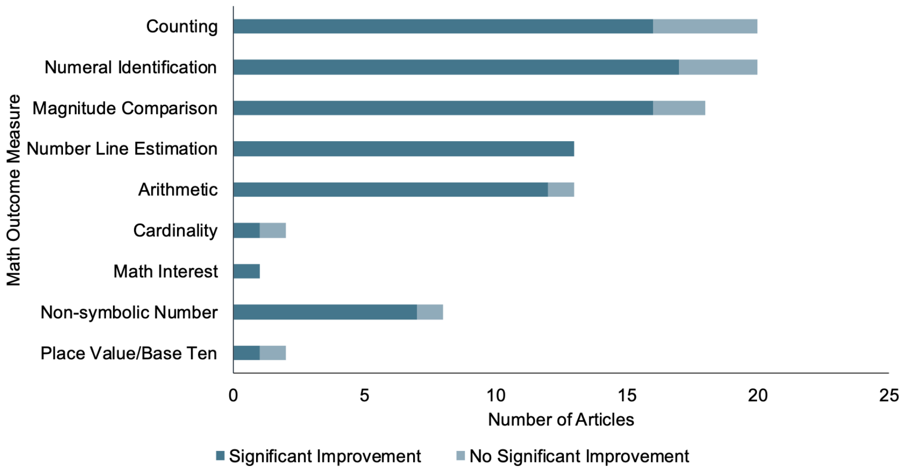
Figure 3

Summary of Math Outcome Measures Studied



Game Type and Content: Card Games

Basic Number Skills — Only one study examined a card game for basic number skills. The game was included as a control comparison to a magnitude comparison card game, which is further described below (Scalise et al., 2018).

Advanced Number Skills — Almost all of the articles examining card games for children's advanced number skills examined numerical card games played like the card game "War," focused on comparing magnitudes. Studies included magnitude comparisons of numbers 1-10, sums of one-digit whole numbers, fractions, and decimals.

For games involving whole numbers, findings suggested that playing the games led to improvements in number and numerical magnitude skills (Scalise et al., 2018; Whyte & Bull, 2008) and addition (Casey et al., 2020), and that the amount of time children played the game related to increases in their skills (Ramani & Scalise, 2020). However, one study found that improvements were only greater than those from a 1-10 matching card game for children's symbolic magnitude comparison skills (Scalise et al., 2018).

For the two studies considering fraction and decimal comparisons, findings indicated that aspects of the game materials and structure (e.g., using formal decimal labels, actively dividing fractions) were most effective at promoting learning (Hurst et al., 2022; Loehr & Rittle-Johnson, 2017).

Game Type and Content: Physical Games/Sets of Games

Basic Number Skills — Similar to the basic number board games described above, one study examining physical games considered a 1-10 embodied number line game (Navarrete et al., 2018). Consistent with results for linear board games, findings indicated that playing the game related to medium- to large-effect-size improvements in tasks involving the numbers 1-10.

Advanced Number Skills — For advanced skills, the majority of articles considered sets of games. Sets included board, card, physical, and other games targeted at number, arithmetic, magnitude comparison, and number relations skills (Chao et al., 2000; de Chambrier et al., 2021). Both studies found that playing games improved kindergartener's early math skills.

Game Type and Content: Summary

These studies indicate that children can learn many math skills from a variety of games, including researcher-developed and commercial games. Board, card, and physical games can lead to improvements in children's basic and advanced skills. This indicates that the benefit of games on children's math learning is not limited to specific game types or levels of math content. Further, although many of the studies focused on games for preschool and kindergarten children's math learning, there is also evidence of older children learning from games. This is important because it demonstrates that games can continue to facilitate math learning throughout development, even as math content becomes more advanced.

Who Learns From Math Games?

The second aim was to examine if math gameplay results in equal learning benefits for all children or if certain subgroups of children might benefit more than others. Five articles were identified which considered differences based on math ability (n = 4), age (n = 2), and SES (n = 1).

Four studies considered the role of children's initial math ability in their learning from games. Two studies found that children with initially lower math ability showed greater gains after gameplay (Ramani & Siegler, 2011; Siegler & Ramani, 2009) and one found that children with initially higher number knowledge improved more (Silver et al., 2024). Another study (de Chambrier et al., 2021) examined games played either only at school or both at school and at home. For children who played games at school, results indicated that children who started with higher math ability improved more. However, for children who played games at school and at home, results indicated that children who started with lower math ability improved more. Together, these findings indicate that math games have the potential to increase math outcomes for all children, with benefits for children of lower math abilities in some cases. This is important, as games provide an engaging context for learning in a way that is accessible to children regardless of math ability.

Two studies (Ramani & Siegler, 2008, 2011) considered the impact of age on children's math learning, specifically examining older and younger preschoolers. For the same numerical board game, they found that both older and younger preschoolers demonstrated the same learning gains, despite starting with initial differences in pretest math scores. This suggests that children are capable of learning from games from an early age.

One study (Ramani & Siegler, 2011) considered differences in learning outcomes by SES. Results indicated that gameplay benefitted children from lower-income backgrounds more than children from middle-income backgrounds.

Overall, these five studies indicate that all children can benefit from 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 can have implications for developing game interventions and using games in early childhood contexts. For example, children performing lower in math may benefit from engaging with math concepts through gameplay. However, as these results are only representative of five studies, more work is needed to further understand how different subgroups of children learn from math games.

What Features of Math Games Effectively Promote Learning?

The third aim was to examine what features of games effectively promote early learning. Eighteen articles were identified for this aim and fell into three categories: game elements (n = 9), game instructions/training (n = 4), and interactions during gameplay (n = 5).

Game Elements

In considering game elements effective for math learning, studies primarily focused on aspects of game design, such as the layout of the game board or the information presented on game materials. For example, four studies examined differences in math learning from playing a linear versus a non-linear game (Elofsson et al., 2016; Ramani & Siegler, 2011; Siegler & Ramani, 2009; Whyte & Bull, 2008). Linearity is important to consider as certain foundational math skills (e.g., number line estimation) build from a linear representation of numbers. In line with this, every study found support for linear games enhancing children's number line estimation abilities more than non-linear games.

In addition, four articles examined differences in math learning related to the labeling and design of game materials (Chao et al., 2000; Hurst et al., 2022; Loehr & Rittle-Johnson, 2017) and the structure of multiple games played with the same materials (Scalise et al., 2018). Findings suggest that the labels and design significantly impacted learning. For example, in a decimal comparison card game, students who played with cards with formal labels (e.g., "two tenths")

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outperformed students who played with cards with informal (e.g., “point two”) or no labels (Loehr & Rittle-Johnson, 2017).

Overall, these 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. These studies also indicate that the same types of games played with differently designed materials, and different games played with the same materials, can impact the math content children learn through play. Together, this suggests that games that include materials, formats, or designs that align with or inherently highlight aspects of the concepts they target can promote children’s learning.

Game Instructions/Training

Four articles investigated the role of game instructions and training on children’s math learning. Specifically, three studies considered specific game instructions for numerical board games. All of these studies examined the effect of having players count on (i.e., counting up from the number of the space they start on when they begin their move). Counting on is hypothesized to support children’s learning because it highlights the numbers and their locations on the board, which may facilitate children’s numerical magnitude understanding.

In two studies, counting on led to greater improvements than counting from one on math measures (Laski & Siegler, 2014; Skillen et al., 2018). The other study found no differences in improvement. However, the authors noted that, of parents surveyed after the intervention, only 50% of parents in the count-on condition actually counted on during gameplay and 21% explicitly said they did not count on (Sonnenschein et al., 2016). This highlights the importance of considering implementation fidelity, as the extent to which game procedures are implemented may influence the extent of children’s learning.

In addition, two studies considered training prior to interventions where families played math games together at home, including the role of training parents (Cheung & McBride, 2017) and children (Sonnenschein et al., 2016). In both studies, children in the condition that received training showed improvements that children in the non-training condition did not.

Overall, these studies of game instructions/training indirectly emphasize the role of structured interactions surrounding gameplay. For example, counting on is not necessarily intuitive for children; however, it allows children to engage in more structured numerical practice while playing, and thus learn more from the games. In addition, the fact that training increases game effectiveness indicates the importance of parent involvement in children’s learning and the potential malleability of parent-child play behavior. Specifically, these studies demonstrate that simple suggestions to increase math engagement during gameplay have the potential to change parent-child gameplay in a way that benefits children’s learning.

Interactions During Gameplay

The majority of studies examining the role of interactions during gameplay on children’s learning considered different aspects of parent guidance. The types of guidance considered included parent scaffolding (i.e., responses and instruction to children such as modeling a counting strategy; Casey et al., 2020; Ramani & Scalise, 2020; Vandermaas-Peeler et al., 2012), use of number words (Ramani & Scalise, 2020), and numeracy interactions (e.g., prompts or information related to numeracy; Vandermaas-Peeler & Pittard, 2014).

Overall, these studies found that certain aspects of parent guidance (e.g., math fact hints, guidance about addition and subtraction) related to children’s math performance. These findings suggest that parent guidance during gameplay can scaffold children’s learning in different ways, and emphasize that different forms of guidance can influence the content and context in which children learn. Parent guidance can include specific types of scaffolding, prompts, use of number words, or discussion of math content, and different types of guidance may benefit different elements of children’s math learning.

Discussion

The current review summarizes the research on the role of math games in early childhood, and provides evidence that playing math games can increase early math knowledge. The results presented align with developmental theories (Piaget, 1950; Vygotsky, 1986), with work showing that children learn from playing games with their parents, peers, and others, and that child engagement and adult guidance relate to children's learning. They also indicate that game elements can be intentionally designed to promote meaningful practice and interactions, which can in turn promote math skills. In addition, the findings presented align with each component of the playful learning theories (Zosh et al., 2018). Specifically, the games in the reviewed studies contextualize math concepts (i.e., make them *meaningful;* Zosh et al., 2018) by putting them into game settings where children can *actively* practice and develop their math and problem-solving skills through repeated (i.e., *iterative*), scaffolded interactions (i.e., *socially interactive)*, that are *engaging* and enjoyable (i.e., *joyful*) (Table 1). This is relevant for early learning at home and in the classroom. The following sections present overall themes of the reviewed studies, gaps in the literature, and future research directions.

Themes, Gaps, and Future Directions

We identified three themes (game design factors, dosage, and math outcomes) which were critical ideas across studies that are important to consider to understand the effects of games. Within our discussion of each theme, we identify critical gaps in the literature and describe game-related and methodological considerations for future work. In considering these, it is important to note that, as described above, our review included only peer-reviewed studies. Accordingly, while our review provides a comprehensive overview of peer-reviewed articles of early math games, it does not include non-peer-reviewed articles or other gray literature, which may show different effects of the role of math games on early math learning.

Game Design Factors

To understand the effects of math games, it is important to understand the game design factors which facilitate learning from games. As described under Aim 3, a subset of the studies reviewed specifically examined how aspects of games and gameplay (e.g., game board design, game materials and structure, game instructions/training, and parent-child interactions during play) related to children's math learning.

Overall, these studies suggest that adapting elements of gameplay to be aligned with the concepts being taught, 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 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 experience with numbers in a linear context. Several studies also demonstrate the role of counting on versus counting from one for children's numerical skills (e.g., Laski & Siegler, 2014; Skillen et al., 2018). In addition, studies of games for numerical magnitude skills highlight the role of having multiple representations of number and magnitude implicit in the game materials (e.g., Scalise et al., 2018). In this way, the game design itself facilitates and scaffolds understanding of the desired math concept (e.g., Laski & Siegler, 2014). This aligns with the playful learning components (e.g., active, iterative, meaningful) and 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. For example, games targeting numerical skills related to base ten understanding could incorporate materials and actions of play that highlight the base ten structure (e.g., 10x10 grids, ten frames).

In addition, studies examining game instructions/training highlight the importance of interactions during gameplay and the quality of gameplay. These findings align with theoretical perspectives on early learning and playful learning opportunities (e.g., Piaget, 1950; Vygotsky, 1986; Zosh et al., 2018). Importantly, many of the instructional differences or training conditions only provided small manipulations that produce large effects, such as simple suggestions of how to incorporate math into gameplay (Cheung & McBride, 2017; Sonnenschein et al., 2016). This suggests that how players engage in the game is malleable to simple recommendations, and highlights the importance of providing guidelines for math gameplay and math-related language and guidance, as these can impact children's learning. Further, understanding how players follow these guidelines is important, as it has implications for how children learn.

Critically, only a few of the reviewed studies included information regarding fidelity to gameplay instructions or intervention procedures (e.g., Navarrete et al., 2018; Sonnenschein et al., 2016). Similarly, only a few studies noted that experimenters or others administering the game interventions were trained (e.g., Elofsson et al., 2016; Ramani et al., 2012; Van Herwegen et al., 2017); however, some descriptions of training and reports of fidelity data were limited. Including these and other measures of implementation fidelity are important for understanding the effects of gameplay, and are especially important in cases where games are played in different contexts, as both interaction styles and fidelity to instructions/training could vary widely depending on the gameplay context. This could be achieved through in-depth observation of gameplay sessions or self-reports from players of their gameplay behaviors and interactions.

In addition, future studies could examine additional game design and individual factors, as these may influence children's ability to engage in and learn from math games. For example, studies could further examine game features such as gameplay complexity (e.g., number of game rules), representation of numerical content (e.g., symbolic, nonsymbolic) in the game materials, and the role of competitive versus cooperative games. In addition, while some studies considered children's math ability, age, and SES (as described in Aim 2), other individual factors may contribute to children's ability to learn from games. For example, children's executive function skills may moderate or relate to differences in children's math learning, as self-regulation/inhibitory control capacities may be required to effectively play a game. In addition, parents' and teachers' math anxiety and beliefs about math (e.g., importance, interest) also have the potential to influence children's learning (Schaeffer et al., 2018; Zippert & Rittle-Johnson, 2020). Importantly, these factors may also interact with children's math ability level. Future studies could also further consider the role of these factors and ways that they interact with children's learning within their zone of proximal development. For example, do differences in children's learning from games based on game features or individual factors vary based on children's initial math ability level?

Dosage

When considering learning from games, it is important to consider the dosage, or amount of time, children spent playing the games, as the amount of play has the potential to interact with other aspects of gameplay, including game design factors. As shown in Table 2, the majority of studies involved interventions ranging from one week to six months.

Understanding dosage of play is important for multiple reasons. First, even short durations of gameplay may have profound impacts on children's math skills. Many of the intervention studies reviewed incorporated gameplay in small increments. For example, single sessions of play could be as short as 5 (Casey et al., 2020), 10 (Elofsson et al., 2016), or 15-20 minutes (Ramani & Siegler, 2008). This is important, as it indicates that games can be effective when they are incorporated into home or school learning in small segments of time.

Understanding dosage is also especially important for games led by non-experimenters (e.g., parents, teachers), as gameplay outside of a controlled research setting may vary more in the amount of time or attention spent on the game. For example, some studies reported wide variability in the amount of time families played together at home, such as differences ranging from 13 to 1035 minutes over weeks of play (de Chambrier et al., 2021; Ramani & Scalise, 2020; Sonnenschein et al., 2016). Because dosage can vary so widely between families, understanding relations between dosage and math learning can provide further information about the mechanisms through which gameplay promotes math development. For example, Ramani and Scalise (2020) found that dosage related to children's learning gains. When children who play the game more also learn more, this can suggest that gameplay itself promotes math learning. However, in cases where dosage is not randomly assigned, it is also important to consider how dosage may be influenced by other factors, such as attitudes towards math (Frank, 2016). Similarly, when the amount of gameplay does not relate to the extent of children's math learning, it is also important to consider the role of additional factors, such as the quality of gameplay and interactions during gameplay, which may impact both dosage and children's math learning.

Further, it is important to consider the long-term effects of interventions, including how long gains in math ability are maintained, and how dosage influences the duration of effects. Three of the reviewed studies included delayed post-testing to consider the duration of observed effects. Two studies found that improvements remained after ~2 months (Ramani & Siegler, 2008; Skillen et al., 2018) and one study did not (Ribner et al., 2023). More work is needed to examine if other types of games and gameplay settings lead to similarly enduring effects and how dosage may relate

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to how long gains are maintained. To do this, studies could include an additional measurement timepoint (e.g., delayed posttest). Understanding these longer-term effects is important because they have implications for how games are used to teach concepts.

Math Outcomes

The studies reviewed included games designed to target both basic and advanced number and math skills. In considering the effectiveness of the games, it is important to consider how children's math skills were measured. As shown in Table 4 and Figure 3, 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 concepts used simpler versions of these measures (e.g., numbers 1-10), and studies of older children and more advanced concepts used more advanced versions (e.g., one-, two-, and three-digit numbers). Many studies also included measures of number line estimation and arithmetic, which were similarly implemented with simple and advanced versions of the tasks.

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 pretest ceiling effects in pretest-posttest designs. Overall, findings indicate that games can be used to improve a variety of numerical skills, at both basic and advanced levels, which demonstrates the breadth of potential uses of games at different levels of math instruction and ability.

Despite this, more research is needed on the effect of games for math concepts beyond these basic and advanced number skills, such as geometry, algebra, measurement, and data analysis. As the focus of this review was on early childhood, it is possible that studies of games for older children may cover these topics. However, as early math includes foundational number and operations, algebra, geometry, measurement, and data analysis, understanding the role of games for these areas is important for supporting math learning and development across all areas of early problem solving (Ginsburg et al., 2008).

Further, in order to consider the effectiveness of games for different math outcomes, future work is needed to consider how effects may vary across game types and settings. Specifically, none of the reviewed studies included direct comparisons of the effectiveness of location of gameplay for children's math learning, and only one study directly examined the social context of play. As gameplay may differ based on the location of play (e.g., home, school), and the social partners engaged in play, it is possible that certain contexts could promote learning more than others for the same math game. Therefore, understanding how game context influences children's learning is important because it is possible that some games may be more suited for use in one context over another. This can be done with studies that experimentally compare the role of different contexts for children's math learning. For example, studies could consider how learning varies when the same game is played either at home or at school or how learning varies when games are played across different social contexts (e.g., playing with one versus multiple other players, playing with other children versus adults).

In addition, while many studies were experimental, math games were often compared to non-math games or non-game math activities. Future research comparing children's learning of the same math concepts across game type(s) or settings would allow for a better understanding of the role of math games for children's learning. For example, a study could compare the effects of a card, board, and physical game targeting the same math concepts. Understanding these differences is important, because game structure can influence children's learning from games, and certain game designs, types, or formats may better support certain math content areas.

Conclusions

Overall, the current review demonstrates that math games played at school and at home support early math learning. Results were consistent for different game types and across children's math ability levels, age, and SES. Further, game elements (e.g., design, instructions) can be manipulated specifically to promote math learning. However, further research is needed to better understand the benefits of games for young children, including comparisons of games across contexts and potential individual, contextual, and game design factors influencing children's learning from games. A greater understanding of how children learn from math games will allow for the development of games designed to improve children's math skills and further promote math learning and engagement in early childhood.

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