Journal of Cognition and Development

ISSN: 1524-8372 (Print) 1532-7647 (Online) Journal homepage: www.tandfonline.com/journals/hjcd20

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To cite this article: Maria-Aikaterini Chatzaki , Valérie-D. Berner & Korbinian Moeller (17 Aug 2026): Influences of Training Length on the Effectiveness of a Game-Based Intervention for Early Mathematical Skills, Journal of Cognition and Development, DOI: 10.1080/15248372.2026.2717131

To link to this article: https://doi.org/10.1080/15248372.2026.2717131

Published online: 17 Aug 2026.

JOURNAL OF COGNITION AND DEVELOPMENT
https://doi.org/10.1080/15248372.2026.2717131

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Influences of Training Length on the Effectiveness of a Game-Based Intervention for Early Mathematical Skills

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ABSTRACT

Game-based learning approaches are effective to facilitate mathematical learning in early years. Given constraints on staff time, this research paper investigated whether a four-session intervention with a linear board game designed to promote mathematical skills of preschool children led to learning outcomes comparable to a longer six-session intervention with the same game. In total, 208 6-year-old German children were randomly assigned to three groups (six game sessions, four game sessions, control). Results indicated that the six-session group achieved significantly larger learning gains in more complex mathematical skills, such as understanding cardinality and the part-whole concept, than the four-session and control group. No significant difference was present between learning gains of the four-session and the control group. These findings suggest that the shorter implementation of the linear board game did not seem to offer sufficient opportunities to train mathematical skills beyond those needed to play the game properly. As such, it is important to ensure enough play time to effectively facilitate early mathematical learning.

1. Introduction

Promoting the development of mathematical skills in early childhood has increasingly become a focus for educators, policy makers, and curricula in many countries (e.g., Bayerisches Staatsministerium für Familie, Arbeit und Soziales, & Staatsinstitut für Frühpädagogik und Medienkompetenz, 2024; National Association for the Education of Young Children & National Council of Teachers of Mathematics, 2002). In this context, game-based approaches, and especially board games, seem to be very promising (Fisher et al., 2013; Gasteiger & Moeller, 2021; Herzog & Fritz, 2022; Ramani & Scalise, 2020; Scalise et al., 2022; Skillen, Berner, & Seitz-Stein, 2018). For instance, Berner et al. (2024) found that playing a board game six times over a period of about 2 weeks had a significant positive effect on children's acquisition of early mathematical skills such as cardinality understanding. Considering demands on time- and resource-efficient interventions for preschool settings (Bock-Famulla et al., 2023a, 2023b), this study explores whether a shorter four-session version of the board game may also be effective in promoting children's early mathematical skills.

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In the following, we first present relevant theoretical background on the development of mathematical skills. Then we discuss the importance of promoting early mathematical skills before we elaborate on how to promote these skills using game-based approaches. After that, we specify our research question on the effectiveness of a shorter intervention using the above-mentioned board game for learning early mathematical skills.

1.1. The development of mathematical skills

Different theoretical models describe mathematical development as hierarchical and discontinuous (Fritz et al., 2018; Krajewski & Schneider, 2009). For example, the model by Fritz et al. (2013, 2018) proposes mathematical development occurs across six levels, with a focus on the development between 4 and 8 years of age. It starts with level 1, reflecting the acquisition of counting skills. At level 2, the mental number line representation develops (Resnick, 1983), upon which numbers are arranged in order of increasing quantity. At level 3, children grasp the cardinality of numbers, which means that they understand that a number word also represents a specific quantity of elements. This understanding of numbers as cardinal entities is expanded to include the idea that numbers can be composed of entities and broken down into them. At level 4, children can understand that a number is made up of individual elements that can also be broken down in different ways (i.e., part-whole understanding; Resnick, 1983). At level 5, children are able to not only compare magnitudes, but also to determine differences between magnitudes, which indicates that they develop an understanding of relationality between numbers. Finally, at level 6 they understand that numbers can be a composition of equally large subsets and thus start developing a multiplicative understanding of numbers (i.e., aspects of bundling and unbundling, e.g., eight consists of two bundles of four and thus “Two times four makes eight”; Fritz et al., 2013).

According to Fritz et al. (2013), the levels of the model are assumed to be hierarchical, meaning that when a child masters level 3 of the model, it is assumed that lower levels have been mastered as well. However, Fritz et al. (2018) also argued that progression within the model is not a strict one-directional process, with mathematical skills being acquired in a strictly hierarchical way. Instead, the development of early mathematical skills is argued to progress in an overlapping waves-like manner (Siegler, 1998). Accordingly, a child may demonstrate different levels of mathematical skills in tasks of varying difficulty or complexity at the same time (Fritz et al., 2018).

1.2. The relevance of promoting early mathematical skills in preschool years

Early mathematical skills, such as counting and cardinality understanding, were repeatedly found to significantly predict later academic achievement (e.g., Gashaj et al., 2023; Koponen et al., 2019; Nogues & Dorneles, 2021; Träff et al., 2023). As such, early mathematical skills are considered domain-specific precursors of later more complex mathematical skills such as arithmetic (e.g., Hirsch et al., 2018; Jordan et al., 2009). Accordingly, not adequately mastering such early mathematical skills and concepts before school entry can lead to difficulties with acquiring more complex mathematical skills and concepts (e.g., learning disabilities in mathematics, such as dyscalculia; Krajewski, 2008).

At the same time, numerous studies indicated considerable heterogeneity in early mathematical skills already before school entry (Anders et al., 2013; Bakker et al., 2023; Devlin et al., 2024). These inter-individual differences seem to be stable or even increase over subsequent school years (Bakker et al., 2023; Morgan et al., 2011; Stern, 2009; Watts et al., 2014) when no specific intervention is provided. This seems to be due to the hierarchical nature of mathematics as a subject with new skills and concepts to be learned building on previously acquired ones (Aunola et al., 2004; Cahoon et al., 2021; Garon-Carrier et al., 2018; Jordan et al., 2007; Morgan et al., 2011; Park & Esposito, 2022), a pattern similar to the Matthew effect in reading (Bast & Reitsma, 1997). Consequently, students with better early mathematical skills at school entry typically show faster progression in acquiring new skills and concepts, whereas children with poorer skills at school entry will develop new skills and concepts more slowly and may thus fall (further) behind. In fact, these children may catch up when they receive additional support – which may be in the form of game-based approaches (Jörns et al., 2014).

Apart from domain-specific, prior research also evaluated interventions targeting domain-general skills to promote early mathematical development. For instance, a set of studies investigated effects of interventions fostering spatial skills, such as mental rotation (e.g., Bower et al., 2025; Gilligan et al., 2020; Mix et al., 2021; Zhang & Gunderson, 2025; for a meta-analysis see also Hawes et al., 2022), or working memory (Ramani et al., 2017, 2020) on children's early mathematical skills. Overall, results seem promising showing some transfer effects to mathematical skills. Nevertheless, intervention effects on mathematical skills were generally smaller than when domain-specific mathematical skills were trained. Accordingly, the present study focused on a domain-specific intervention, utilizing game-based approaches to promote early mathematical skills.

1.3. Game-based approaches to promote early mathematical skills

There is accumulating evidence that game-based approaches to promote early mathematical skills before school entry are effective and can have sustainable effects (e.g., Cohrssen & Niklas, 2019; Herzog & Fritz, 2022; Jörns et al., 2014; Laski & Siegler, 2014; Seeger et al., 2018; Vogt et al., 2018). Importantly, such game-based approaches commonly follow ideas of guided play, which comes with several advantages. First, these approaches are typically characterized by a structured setup led by an adult, but driven by children, and incorporating clear learning goals (Weisberg et al., 2013). Furthermore, they typically offer scaffolding and keep participating children engaged in actively manipulating and processing mathematical information (Nesbitt et al., 2023; Seeger et al., 2018; Skene et al., 2022; Zosh et al., 2018). Also, game play situations often can initiate co-constructive and communicative processes, in which children maintain attention on mathematical concepts, link new mathematical concepts to previously acquired ones, and start transferring skills and concepts to everyday life situations (Fthenakis, 2009; Nesbitt et al., 2023; Skene et al., 2022; Zosh et al., 2018).

Interestingly, however, previous game-based mathematical interventions were realized in very different ways. Some studies created or modified existing games (Hauser et al., 2014; Jörns et al., 2013; Lange et al., 2020; Ramani et al., 2012; Vogt et al., 2018), while others supplemented games by working with picture books (Hassinger-Das et al., 2015; Seeger et al., 2018; see also Purpura et al., 2024, 2021 for interventions using storybooks only) and rhymes (Young-Loveridge, 2004) and, in some cases, commercially available games were used (Gasteiger, 2015; Gasteiger & Moeller, 2021). In many cases, linear number board games were used. For example, Ramani and Siegler (2008) had children play a linear number board game for four game sessions. In comparison to a color-based board game, children playing the linear number board game presented significantly more pronounced improvements in counting, number line estimation, numerical magnitude comparison, and numerical identification. Whyte and Bull (2008) found comparable results after running a number board game intervention over four game sessions in small groups. In particular, they compared a group playing a linear number board game to a group playing a number card game and a group playing a linear color board game. They observed that both groups playing number games showed significantly stronger improvements in their counting abilities, magnitude understanding, and ability to recognize and name Arabic symbols. However, only those playing the linear number board game showed significantly more pronounced improvement in number line estimation. This indicates that the linear spatial layout of the game probably supported the numerical estimation accuracy.

Generally speaking, prior empirical evidence suggests that playing linear number board games seems particularly promising in facilitating the development of early mathematical skills (Elofsson et al., 2016; Lange et al., 2020; Laski & Siegler, 2014; Ramani & Siegler, 2008; Ramani et al., 2012; Skillen, Berner, & Seitz-Stein, 2018; Skillen, Berner, Ricken, et al., 2018; Whyte & Bull, 2008). Linear number board games, such as the *House of Numbers* (Skillen, Berner, & Seitz-Stein, 2018), provide players with multiple correlated cues relating to numerical magnitude. These include visuospatial, temporal, kinesthetic, and/or verbal cues, which help players establish their mental representation of numerical magnitudes (Siegler & Booth, 2004).

1.3.1. The House of Numbers-20

Comparable to the commercial board game Snakes and Ladders, *House of Numbers-20* (Berner et al., 2022, 2024) is characterized by having uniformly sized squares arranged in a continuous and consecutively numbered way covering the number range up to 20 (see Figure 1). The aim of the game is for each player to move along all squares on the *House of Numbers-20* board and reach the finish first. To do so, each player has to roll a 10-sided die during their turn and move their pawn along the board according to the number shown on the die face. The die is marked with the Arabic digits one to five, with each digit appearing twice across the ten sides.

Moving along the board employs the count-on rule (Laski & Siegler, 2014). According to this rule, rather than starting at one and counting upward for each step when moving their pawn, players must name the numbers on the respective squares of the board as they move along them (see also *Game-based training of early mathematical skills*). By requiring players to move their pawn along the board using specific counting strategies, such as the count-on rule, games like *House of Numbers-20* offer numerous clues that facilitate deeper comprehension of the sequence and magnitudes of the numbers presented (e.g., Laski & Siegler, 2014; Siegler & Ramani, 2009).

As with many board games, *House of Numbers-20* includes some further special features. For instance, there are three dedicated squares on the board (i.e., 9, 12, and 18). When players land on or move over these squares, they have to pick an action card and solve the

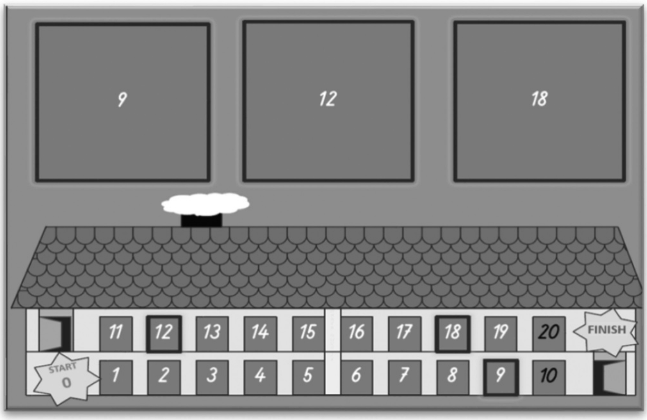

Figure 1. The game board of the game House of Numbers-20. *Note*. The lower part of the board features the house with the numbers living behind each door. The upper part of the board is designated for the stacks of action cards, which players draw from whenever they land on or pass over the designated squares numbered 9, 12, and 18.

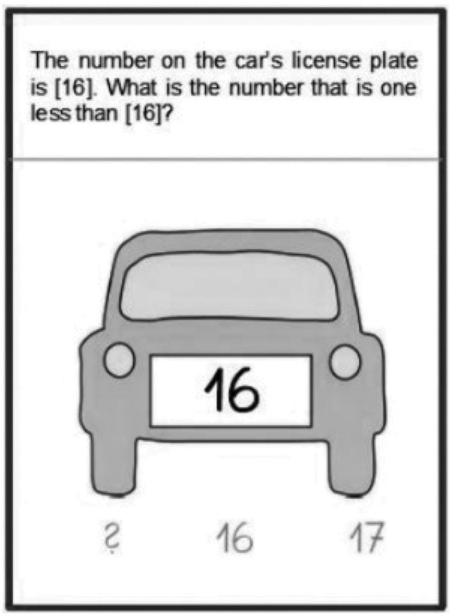

Figure 2. Example of an action card from the game House of Numbers-20.

mathematical problem given on the card (e.g., they see a picture of some fish and have to count the fish; see also Figure 2 and Berner et al., 2022 for more details).

The version of *House of Numbers-20* used in this study builds on the model of the development of numerical concepts by Fritz et al. (2013; see also Skillen, Berner, & Seitz-Stein, 2018). Playing *House of Numbers-20* addresses early mathematical skills mainly associated with the first three levels of this model through the interaction with game elements such as the linear board, the Arabic digit die, the count-on rule, and the additional problems posed by respective action cards. In particular, as children move their pawn along the game board, they must recite the numbers on the squares. In particular, counting on squares using the count-on rule and counting out specific quantities according to a quest on an action card address mathematical skills referred to level 1 of the model by Fritz et al. (2018).

The linear layout of the squares on the board further supports the development of a number line representation (level 2). This is to promote children's understanding that each number denotes a position on a linear continuum, upon which each position is linked by a "successor" or "next" relationship and a directional marker on the continuum indicating that later positions reflect larger numbers (Resnick, 1983).

Moreover, as children need to read the die, they learn to associate respective magnitude information with Arabic digits and verbal number words when they establish how far to move their token along the board. This promotes their understanding of cardinality (level 3). Additionally, when children start understanding and keep track of how many squares there are left until they reach the number indicated on the die, they acquire the idea of decomposing numbers into smaller ones (level 3).

As suggested by Fritz et al. (2018), the majority of children should be developing through level 2 (i.e., mental number line) about half a year before the start of first grade. In Germany, this corresponds to an age of around 6 years, at which children typically attend childcare facilities called "Kindergarten" right before they start primary school. At around the same age, a smaller number of children would have reached level 1 (counting) only or level 3 (understanding cardinality and decomposability) already. Accordingly, the current intervention specifically targeted early mathematical skills associated with the first three levels of the model by Fritz et al. (2013, 2018) through game-play actions including action cards.

1.4. An economical and nuanced linear board game approach

Previous studies have demonstrated the effectiveness of *House of Numbers-20* for small group settings (Berner et al., 2022, 2024). Children who completed six game sessions of approximately 10 to 20 minutes each showed significant learning gains in skills associated with levels 3, 4, and 5 of the model by Fritz et al. (2013, 2018) compared to a business-as-usual control group (Berner et al., 2024). In particular, results indicated that children understood the concepts of cardinality and decomposability (level 3), part-whole relations (level 4), and the relationality between numbers (level 5) significantly better after completing the game intervention. The observed learning gains for early mathematical skills associated with levels 4 and 5 of the model by Fritz et al. (2013, 2018) are specifically interesting as these improvements seem to reflect some sort of transfer-like effects to skills and concepts not directly addressed in the game play. Nevertheless, it is well conceivable how these skills may develop implicitly while playing the game for longer and having mastered more basic skills required for playing the game. For instance, when a child rolls a 5, it might recognize that there are two squares to move before arriving at the designated square, and three more squares to travel after that, until reaching the final square for their turn (level 4). Accordingly, a child may also determine and understand that it stands two squares ahead with its red token compared to the blue token of another player (level 5).

Importantly, however, the primary factor limiting specific interventions in childcare facilities typically comes down to staffing and related time constraints (e.g., Bock-Famulla et al., 2023a, 2023b). This situation highlights the need for time- and resource-efficient interventions. As regards game-based interventions for early mathematical skills, previous studies implemented board game interventions of varying lengths, ranging from four to 27 small group sessions, each lasting between 10 and 30 minutes (Elofsson et al., 2016; Gasteiger & Moeller, 2021; Lange et al., 2020; Laski & Siegler, 2014; Ramani et al., 2012; Skillen, Berner, Ricken, et al., 2018; Whyte & Bull, 2008). In addition, prior studies that have used linear number board game interventions in four sessions either played them individually (Laski & Siegler, 2014; Ramani & Siegler, 2008) or used games with gradually increasing levels of difficulty (Whyte & Bull, 2008). However, there is hardly any evidence comparing the effectiveness of a successful game-based intervention for different training lengths. For example, it is not yet clear whether a shorter intervention using *House of Numbers-20* would still yield significant learning gains or not. Hence, the present study set off to evaluate whether an intervention with only four sessions of playing *House of Numbers-20* yields learning gains comparable to the six game sessions.

1.5. The present study

Taken together, accumulating evidence indicates that early mathematical skills are essential for further academic progression. Furthermore, their early promotion applying game-based approaches was found effective, in particular when playing (linear) board games, such as *House of Numbers-20*. However, considering time and resource constraints in childcare facilities, the current study aimed at evaluating whether a shortened intervention with only four game sessions would still yield significant learning gains compared to a six-session game intervention and a business-as-usual control group. In line with the results of Berner et al. (2024), we expected (1) significant improvements primarily for early mathematical skills directly addressed in the game such as understanding cardinality and decomposability (level 3) as these need to be mastered to successfully play the game. (2) With respect to learning gains for more advanced early mathematical skills only implicitly addressed in the game such as part-whole relations (level 4), and relationality between numbers (level 5), it might be that the shorter four-session game intervention may not yield learning gains comparable to the six-session version as such transfer-like effects may take longer to establish.

2. Method

2.1. Participants

To participate in the study, children had to have a sufficient understanding of German to guarantee test comprehension. One child was directly excluded from the study due to insufficient language skills identified through difficulties in understanding the instructions during pretest. A total of 226 children participated in this study. Data of 14 children (6.19%) had to be excluded as these children missed the posttest – primarily because of illness or being on vacation. Data of another four children were excluded from analyses because they did not participate in the respective number of game sessions. Thus, the final sample of this study consisted of 208 children (109 girls, 99 boys, mean age 6.04 years, SD_{age} = 0.38, in their last year before school entry). Children were recruited from 31 childcare facilities in southern Germany. The study considered ethical guidelines of the American Psychological Association (APA) and the German Psychological Society (DGPs) and was approved by the research university ethic committee. Participation was voluntary and only children whose parents provided written informed consent before the start of the study and who themselves gave verbal consent before each session of the study were considered. Data on the children's age and sex were collected through a short questionnaire, which was included in the written informed consent form completed by parents.

Our intention was to randomly assign all participating children in each childcare facility to one of three groups, with all three groups represented in each childcare facility, across the three waves of data collection. However, due to organizational reasons (e.g., dropping-out of childcare facilities, availability of childcare facilities on restricted days of the week, partly restricted number of experimenters available, no-shows of children due to sickness or family reasons) this was not possible. Therefore, we arranged to have at least one intervention group (comprising either four or six game sessions) and one control group in each childcare facility. Accordingly, children in each participating childcare facility were randomly assigned to either an intervention or a control group, with children from different classrooms within the same childcare facility being mixed into the two conditions. This led to the six-session group ultimately having fewer participants than the other two groups and children being randomized into conditions at the childcare facility level. That means, in each childcare facility children among classrooms were mixed into one intervention (either four or six game sessions) and one control group. The group that participated in six game sessions included 56 children (28 girls, 28 boys, mean age 6.01 years, SD_{age} = 0.37 months). The group that participated in four game sessions involved 79 children (40 girls, 39 boys, mean age 6.07 years, SD_{age} = 0.40). And the control group consisted of 73 children (41 girls, 32 boys, mean age 6.03 years, SD_{age} = 0.37).

2.2. Materials

2.2.1. Assessment of early mathematical skills

Children's early mathematical skills were assessed by the standardized test *Mathematik- und Rechenkonzepte im Vorschulalter-Diagnose* [Preschool mathematics and numeracy concepts – Diagnosis] (MARKO-D; Garrote & Opitz, 2021; Ricken et al., 2013). The test consists of 55 items, which are presented in a fixed order and vary in difficulty. These tasks are framed in an age-appropriate narrative featuring two squirrels named Ben and Lisa. Each item is assigned to one of the first five levels of the model by Fritz et al. (2013). The experimenter marks each item as completed correctly or not and awards one point for each correctly solved item. The sum of all correctly solved items reflects the total score. This total score allows for comparison with the respective age group using standardized norms available for different age groups in six-month intervals.

In this study, in addition to calculating and considering the total score for our analyses, we also grouped items associated with specific levels to create subscores for each of the five levels (see Table 1 for number of items at each level). Cronbach's alpha for the total score in this study was .90 at the first measurement time point (between .68 and .79 on subscale level) and .91 at the second (between .64 and .82 on subscale level).

Table 1. Statistical details for group differences in performance gains between pre and posttest separated for groups and levels of the model by Fritz et al. (2013) as well as the total score.

Level	*N* of items	*F*	η_p^2	Group	Pretest *M (SD)*	Posttest *M (SD)*	Gain score	*t*	*df*	*p*	Cohens *d*
Level 1	16	8.44***	.076	Six games	13.59 (2.21)	13.46 (1.31)	−0.13	0.67	55	.507	0.09
				Four games	14.89 (1.48)	15.29 (1.49)	0.41	2.66	78	.010	0.30
				Control	14.81 (2.20)	15.05 (1.52)	0.25	1.47	72	.145	0.17
Level 2	10	0.79	.008	Six games	7.79 (2.15)	8.16 (1.89)	0.38	1.69	55	.096	0.23
				Four games	7.62 (2.37)	8.20 (1.86)	0.58	2.86	78	.005	0.32
				Control	7.27 (2.60)	8.15 (2.11)	0.88	3.99	72	<.001	0.47
Level 3	12	0.22	.002	Six games	7.20 (2.71)	9.13 (2.32)	1.93	8.47	55	<.001	1.13
				Four games	7.43 (2.59)	8.61 (3.05)	1.18	4.64	78	<.001	0.52
				Control	7.51 (2.89)	8.18 (2.86)	0.67	2.94	72	.004	0.34
Level 4	5	4.63*	.043	Six games	1.46 (1.43)	3.02 (1.73)	1.55	6.50	55	<.001	0.87
				Four games	2.24 (1.62)	2.84 (1.76)	0.60	4.25	78	<.001	0.48
				Control	2.19 (1.66)	2.63 (1.77)	0.44	3.06	72	.003	0.36
Level 5	12	3.39*	.032	Six games	1.82 (2.05)	3.25 (2.18)	1.43	5.23	55	<.001	0.70
				Four games	2.87 (2.79)	3.85 (3.10)	0.98	4.21	78	<.001	0.47
				Control	2.90 (2.81)	3.81 (3.56)	0.90	3.76	72	<.001	0.44
Total score	55	2.53^{+}	.024	Six games	31.86 (7.48)	37.02 (7.47)	5.16	9.08	55	<.001	1.21
				Four games	35.05 (8.20)	38.78 (8.98)	3.73	7.26	78	<.001	0.82
				Control	34.68 (9.87)	37.82 (9.50)	3.14	5.56	72	<.001	0.65

Note. F-values from ANOVA testing for group differences at pretest. $^{+}p < .10$, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$. $df = 2$, $df_{Error} = 205$. Six-session group $n = 56$, four-session group $n = 79$, control group $n = 73$.

2.2.2. Game-based training of early mathematical skills

The linear board game *House of Numbers-20* (Berner et al., 2022, 2024) was used to facilitate early mathematical skills (see also *The House of Numbers-20*). The game board displays a house with 20 numbered squares, where each square represents a door (see Figure 1), embedded in a story about 20 numbers living behind these doors.

During game sessions of approximately 20 minutes each, a trained experimenter played the game with a small group of two to three children each. As the game is played in turns, all children participated equally in the game. In the first game session, the experimenter introduced all game elements and rules in a standardized manner. In particular, to introduce the count-on rule, players were instructed that the numbers are very happy when players say their name whenever they walk past their door. For example, when the pawn of a player is standing on the third door and the player rolls a 2, the player should say: "I have rolled a 2. So, I can walk past door 4 to door 5. So, I walked on two doors from door 3." When it was the experimenter's turn, the whole group was instructed to say this out loud together. During the subsequent game sessions, the experimenter first asked the participating children whether they can still remember the rules of the game, offering support to ensure that everyone is up to date. During each game session, the experimenter ensured that all rules were being followed. In case a child answered an activity card question incorrectly, the experimenter offered the child a second chance. When the child answered incorrectly again, the next child was called upon, and this continued until the correct answer was given.

2.3. Procedure

Data was collected in three waves from 2022 to 2024, starting each spring. In each wave, there were two intervention groups and a business-as-usual control group to which children were assigned randomly. Children of the first intervention group completed six sessions playing *House of Numbers-20* over a period of approximately two weeks. Children assigned to the second intervention group completed four sessions within about two weeks playing *House of Numbers-20*. The business-as-usual control group did not receive any intervention beyond standard activities delivered at their childcare facilities during the respective period. Mathematical skills of all participating children were assessed individually before (pretest) and after the game sessions (posttest). All assessment and gameplay sessions took place in separate rooms within the respective childcare facilities during regular operating hours.

2.4. Analytic strategy

We first ran preliminary analyses to check for pretest differences between the three groups regarding age and early mathematical skills. Additionally, we checked for potential gender differences in early mathematical skills. We then evaluated our research questions as to whether children who participated in interventions of different lengths would differ in their learning gains overall (considering the total math score as well as differentially for the specific levels of numerical development according to the model by Fritz et al. (2013, 2018).

Accordingly, we conducted analyses of covariance (ANCOVAs) evaluating influences of the factor group (six game sessions, four game sessions, control) on children's posttest scores (as dependent variable; i.e., total score and for each subscore achieved at posttest) while considering the score achieved at pretest as covariate (total or respective subscore).

When determining sample size, the goal was to obtain a sample at least as large as those used in previous studies evaluating the *House of Numbers-20* (i.e., 79 in Berner et al., 2022, 2024). Sensitivity analysis determined the minimum effect size that our design and sample size was sufficiently sensitive to detect (Faul et al., 2007). The analysis indicated that with the current sample size and an expected power of .80, an ANCOVA could reliably detect a minimum effect of $\eta_p^2 = .046$, which corresponds to a medium sized effect (Cohen, 1988). All analyses in this study were run using SPSS 29.0.2.0 (IBM Corp [IBM], 2023) and G*Power 3.1.9.7 (Faul et al., 2009).

3. Results

3.1. Preliminary analyses

The three groups did not differ significantly in age $F(2, 205) = 0.53$, $p = .587$, $\eta_p^2 = .005$. Additionally, gender was evenly distributed across groups χ^2 (2) = 0.64, $p = .725$, V = .06. Unexpectedly, across all groups, girls ($M = 14.83$, $SD = 1.47$) performed significantly better than boys ($M = 14.15$, $SD = 2.47$) on level 1 tasks at pretest; $t(163.01) = 2.45$, $p = .015$, $d = .34$. However, when gender was included as a covariate in each of the ANCOVA analyses, it showed non-significant effects, and the overall results remained unchanged.

Furthermore, as displayed in Table 1, although there was no significant difference in total math score at pretest between groups, the three groups did show significant differences at pretest on tasks addressing levels 1, 4, and 5. In particular, as seen in Table 1, both the group completing four game sessions and the control group scored significantly better than the group completing six game sessions at these levels (see also Table 2 for pairwise comparisons). This finding suggests that differences in math performance between groups existed

Table 2. Bonferroni-corrected pairwise comparisons of pretest scores per level addressed.

					95% CI	
Level	Pair	Mean difference	*SE*	*p*	Lower	Upper
Level 1	Six games – four games	−1.30	0.34	.001	−2.12	−0.47
	Six games – control	−1.22	0.35	.002	−2.06	−0.38
	Four games – control	0.08	0.32	1.000	−0.69	0.85
Level 2	Six games – four games	0.17	0.42	1.000	−0.85	1.18
	Six games – control	0.51	0.43	.694	−0.52	1.54
	Four games – control	0.35	0.39	1.000	−0.59	1.29
Level 3	Six games – four games	−0.23	0.47	1.000	−1.38	0.91
	Six games – control	−0.31	0.48	1.000	−1.48	0.85
	Four games – control	−0.08	0.44	1.000	−1.14	0.99
Level 4	Six games – four games	−0.78	0.28	.017	−1.44	−0.11
	Six games – control	−0.73	0.28	.032	−1.41	−0.05
	Four games – control	0.05	0.26	1.000	−0.57	0.67
Level 5	Six games – four games	−1.05	0.46	.068	−2.16	0.05
	Six games – control	−1.08	0.47	.063	−2.21	0.04
	Four games – control	−0.03	0.43	1.000	−1.06	1.00
Total score	Six games – four games	−3.19	1.51	.107	−6.84	0.45
	Six games – control	−2.83	1.54	.201	−6.54	0.88
	Four games – control	0.37	1.40	1.000	−3.02	3.75

before the intervention, substantiating the importance of controlling for this aspect in further analyses.

3.2. Learning gains across groups

All groups showed a significant increase in their total math score over time. However, as reflected in Table 1, the effects differed across tasks of specific levels. In particular, only children participating in four game sessions showed a significant increase in their performance on early mathematical skills associated with level 1 tasks (i.e., counting related). For early mathematical skills associated with level 2 (i.e., number line related), only children participating in four game sessions and from the control group showed significant learning gains. In contrast, all groups showed significant learning gains for early mathematical skills associated with the remaining higher levels.

3.3. Learning gain differences for total score and levels

Results of separate ANCOVAs for the total score as well as individual levels indicated differential results across levels. Please note that the following analyses compare performance gains on respective tasks associated with individual levels of the model by Fritz et al. (2013, 2018) between the groups completing six game sessions ($n = 56$), four game sessions ($n = 79$), and the control group ($n = 73$). As indicated by Table 3, no significant group differences were observed for the total score, level 2 and level 5 of the model of early mathematical skills. In contrast, analyses indicated significant group differences in posttest scores for early mathematical skills associated with levels 1, 3, and 4 (see Figure 3).

As shown in Table 4, Bonferroni-corrected pairwise comparisons indicated that the group participating in six game sessions showed significantly lower posttest scores at level

Table 3. ANCOVA results per level addressed.

Dependent variable	Effect	*F*	*df*	η_p^2
Level 1	Group	20.34***	2	.166
	Pretest score	201.65***	1	.497
Level 2	Group	0.57	2	.006
	Pretest score	173.75***	1	.460
Level 3	Group	6.07**	2	.056
	Pretest score	238.65***	1	.539
Level 4	Group	7.75***	2	.071
	Pretest score	149.97***	1	.424
Level 5	Group	0.63	2	.006
	Pretest score	263***	1	.563
Total score	Group	2.20	2	.021
	Pretest score	591.74***	1	.744

Note. $^*p < .05$, $^{**}p < .01$, $^{***}p < .001$. $df_{Error} = 204$.

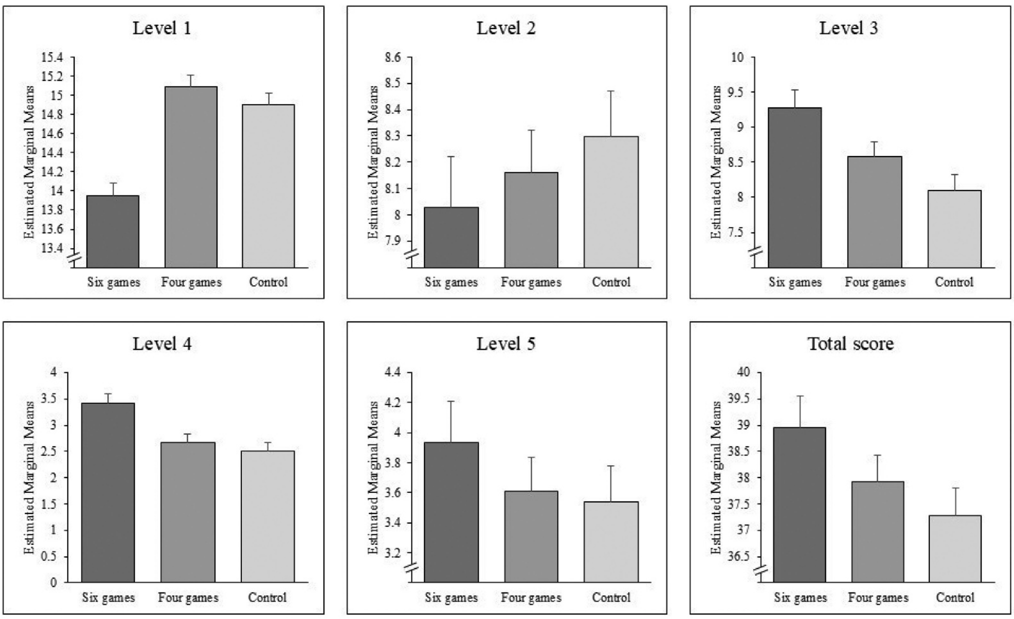

Figure 3. Estimated marginal means at posttest for each group after controlling for pretest performance. *Note.* Error bars represent the respective standard error of the mean (SEM).

1 compared to the group participating in four games and the control group. There was no significant difference in posttest scores between the group participating in four game sessions and the control group.

In contrast, at level 3, the group completing six game sessions presented significantly higher posttest scores compared to the control group but not compared to the four-session group. Again, there was no significant difference between the group participating in four game sessions and the control group.

The posttest scores for mathematical skills associated with level 4 were significantly more pronounced in children participating in six game sessions as compared to the group participating in four game sessions and the control group. Similarly to level 3, there was

Table 4. Bonferroni-corrected pairwise comparisons of posttest scores per level of the model by Fritz et al. (2013) controlled for pretest scores.

					95% CI	
Level	Pair	Mean difference	*SE*	*p*	Lower	Upper
Level 1	Six games – four games	−1.15	0.19	<.001	−1.60	−0.70
	Six games – control	−0.95	0.19	<.001	−1.41	−0.50
	Four games – control	0.20	0.17	.736	−0.21	0.60
Level 2	Six games – four games	−0.13	0.25	1.000	−0.74	0.48
	Six games – control	−0.27	0.26	.868	−0.87	0.35
	Four games – control	−0.10	0.24	1.000	−0.71	0.43
Level 3	Six games – four games	0.70	0.33	.115	−0.11	1.50
	Six games – control	1.18	0.34	.002	0.36	2.00
	Four games – control	0.49	0.31	.351	−0.26	1.24
Level 4	Six games – four games	0.74	0.24	.006	0.17	1.32
	Six games – control	0.93	0.24	<.001	0.33	1.50
	Four games – control	0.17	0.22	1.000	−0.35	0.69
Level 5	Six games – four games	0.33	0.36	1.000	−0.54	1.19
	Six games – control	0.39	0.37	.853	−0.49	1.28
	Four games – control	0.07	0.33	1.000	−0.73	0.86
Total score	Six games – four games	1.03	0.79	.573	−0.87	2.94
	Six games – control	1.68	0.80	.112	−0.25	3.61
	Four games – control	0.64	0.73	1.000	−1.11	2.39

no significant difference in posttest scores of level 4 between the four game sessions and the control group.

4. Discussion

The aim of this study was to evaluate whether a board game intervention using *House of Numbers-20* would still yield significant learning gains for German 6-year-old children when played in four as compared to six game sessions (which was observed to lead to significant learning gains; e.g., Berner et al., 2024). Furthermore, we were interested in whether learning gains were consistent or differed across the first five levels of mathematical development according to the model by Fritz et al. (2013). This was of specific interest because only the first three levels of the model (i.e., counting, number line, and cardinality understanding) were explicitly addressed in *House of Numbers-20* in that they need to be mastered to successfully play the game.

We observed significant improvements in early mathematical skills between pre- and posttest across both intervention as well as the control group with respect to the total math score. However, after controlling for pretest performance, results were more differentiated when looking at different levels of mathematical skills. In particular, both the group participating in four game sessions and the control group had significantly more pronounced learning gains than the group participating in six game sessions for early mathematical skills associated with level 1 (i.e., counting related). In contrast, the group that completed six game sessions demonstrated significantly larger learning gains at level 3 (i.e., related to cardinality) compared to the control group and also showed larger gains than the other two groups at level 4 (i.e., related to the part-whole concept). At the same time, there was no significant difference between learning gains for the group participating in four game sessions and the control group for early mathematical skills associated with any level.

Our findings largely replicate the findings of Berner et al. (2024) for preschool children who participated to an intervention using *House of Numbers-20* similar to the present study. In particular, children which played *House of Numbers-20* for six sessions showed significant differences in pre-to-post intervention learning gains, especially on tasks associated with level 3 (i.e., cardinality related) when compared to a control group. This pattern of results raises the question why the longer version of the game predominantly led to more pronounced learning gains for early mathematical skills associated with level 3 and level 4, reflecting increases in children's understanding of cardinality and the part-whole concept.

One possible explanation is that, as these advanced levels are not comprehensively targeted by the game, they probably simply had more time to develop over the course of six sessions. This might be because foundational mathematical skills required for these levels had already been established through repeated practice in earlier game sessions. That is, the prolonged engagement with the game presumably allowed children to benefit more from its specific features, as well as from the collaborative learning atmosphere with peers and the adult facilitator during gameplay. Essentially, they received more training. As a result, this extended practice in six game sessions probably goes beyond the basic math skills required merely to play the game (e.g., reading the digits on the die or counting out squares until the pawn reaches the goal). Consequently, children probably benefit in their mathematical skills development from longer exposure to mathematical content during playing the game.

On the other hand, children completing the longer version of the game-based intervention with six sessions did not exhibit significant learning gains on the lower levels of the model such as level 1. Regarding this finding, it may be assumed that children in the six-session group have been developing further and therefore started to use more complex problem-solving strategies which are required to be able to solve more complex arithmetic problems. At the same time, they may no longer have applied simpler strategies which would be more effective for solving basic problems addressing lower levels of arithmetical development as suggested by the overlapping waves model proposed by Siegler (1998). This may be similar to what is observed when children learn a new arithmetic operation, such as multiplication. A consequence of learning the new operation is that performance on a previously acquired operation, such as addition, often decreases (Miller & Paredes, 1990). This means that the process of effectively switching between different solution strategies has not yet been automated.

Finally, the finding that learning gains did not differ significantly between children who participated in four sessions and the control group across all levels may also indicate that four sessions do not seem sufficient to efficiently facilitate learning early mathematical skills beyond business as usual. This implies that four sessions were simply not enough to significantly promote mathematical skills and to apply what was learned automatically. Our results therefore suggest that more sessions (e.g., six) may be needed to apply what was learnt.

4.1. Limitations and future research

When interpreting the results of this study, it is important to consider some limitations. First, it is important to note that the four-game-session and the control group showed significantly higher pretest scores on levels 1, 4 and 5 compared to the six-game-session group. However, as all analyses comparing learning gains between groups controlled for pretest performance, we are confident that these did not bias our results in one or the other direction. Furthermore, to rule out the possibility that other individual factors may also affect the acquisition of early mathematical skills during the intervention period, other cognitive abilities known to contribute significantly to mathematical learning should be controlled for in future studies. In particular, general cognitive ability in terms of nonverbal intelligence, but also phonological awareness and/or working memory may be important aspects to control in future studies (Amland et al., 2025; De Vita et al., 2022; Träff et al., 2020). In addition, this study did not include a follow-up assessment to evaluate potential long-term effects of the game-based intervention. As such, we cannot tell whether effects of the game-based intervention were sustainable and thus the group that played six game sessions might even continue to benefit more than the other groups in the long term. Future studies are needed to evaluate this in a longitudinal set-up. Finally, one general limitation of group activities is the inherent variability in individual experiences. Although *House of Numbers 20* is played in turns, allowing for equal participation, some children might inadvertently experience varying degrees of exposure to the game's benefits. However, this is difficult to control for.

Of course, there are other interesting aspects worth examining in future studies. For example, although instructions the experimenters provided during game sessions were standardized and therefore informed about the scaffolding provided, the mathematical talk of participating children during game sessions was not documented. Using a combination of quantitative and such qualitative data in future studies would offer deeper insights into what happens during game sessions – in particular with respect to whether children explore higher-order mathematical concepts while playing the game. Lastly, this study used an analogue linear board game. Given the plethora of digital game interventions designed to enhance early mathematical skills (e.g., Kiili et al., 2018; Lin, 2022; Niklas et al., 2025; Papadakis et al., 2018), a logical next step would be to evaluate a digital version of *House of Numbers-20* for group settings and investigate the same research question on influence of training duration.

5. Conclusions

In sum, current research highlights the relevance of promoting early mathematical skills before entering school (Gashaj et al., 2023; Koponen et al., 2019; Nogues & Dorneles, 2021; Träff et al., 2023). In particular, game-based approaches like linear board games were found effective to promote these skills (Berner et al., 2022 2024; Gasteiger & Moeller, 2021; Siegler & Ramani, 2009). However, constraints on time and staff resources ask for short and time efficient interventions. The results of this study showed that the effectiveness of the game is influenced by the duration of the intervention, with more game sessions leading to significantly more pronounced learning gains, in particular on more advanced levels of mathematical skills. This finding speaks for the use of linear board games such as *House of Numbers-20* in preschool settings on a regular basis, especially when higher levels of early mathematical development are targeted.

Acknowledgments

We are grateful to Prof. Katja Seitz-Stein, former chair of Developmental and Educational Psychology at the Catholic University of Eichstätt-Ingolstadt, for her guidance and recommendations during the planning stages of the project. Additionally, we are thankful to all the children, their parents, and the supportive students who participated in our research. Their indispensable contributions have been fundamental to the success of our study.

Author contributions

CRediT: **Maria-Aikaterini Chatzaki:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; **Valérie-D. Berner:** Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review & editing; **Korbinian Moeller:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

Amland, T., Grande, G., Scherer, R., Lervåg, A., & Melby-Lervåg, M. (2025). Cognitive factors underlying mathematical skills: A systematic review and meta-analysis. *Psychological Bulletin*, *151*(1), 88–129. https://doi.org/10.1037/bul0000457

Anders, Y., Grosse, C., Rossbach, H. G., Ebert, S., & Weinert, S. (2013). Preschool and primary school influences on the development of children's early numeracy skills between the ages of 3 and 7 years in Germany. *School Effectiveness and School Improvement*, *24*(2), 195–211. https://doi.org/10.1080/09243453.2012.749794

Aunola, K., Leskinen, E., Lerkkanen, M. K., & Nurmi, J. E. (2004). Developmental dynamics of math performance from preschool to grade 2. *Journal of Educational Psychology*, *96*(4), 699–713. https://doi.org/10.1037/0022-0663.96.4.699

Bakker, M., Torbeyns, J., Verschaffel, L., & DeSmedt, B. (2023). Longitudinal pathways of numerical abilities in preschool: Cognitive and environmental correlates and relation to primary school mathematics achievement. *Developmental Psychology*, *59*(3), 442–459. https://doi.org/10.1037/dev0001491

Bast, J., & Reitsma, P. (1997). Mathew effects in reading: A comparison of latent growth curve models and simplex models with structured means. *Multivariate Behavioral Research*, *32*(2), 135–167. https://doi.org/10.1207/s15327906mbr3202_3

Bayerisches Staatsministerium für Familie, Arbeit und Soziales, & Staatsinstitut für Frühpädagogik und Medienkompetenz. (2024). *Der Bayerische Bildungs- und Erziehungsplan für Kinder in Tageseinrichtungen* [The Bavarian education und upbringing plan for children in day care facilities] (11th ed.). Cornelsen.

Berner, V. D., Niklas, F., Chatzaki, M. A., & Seitz-Stein, K. (2024). Play-integrated fostering of basic mathematical skills: Findings of two experiments. *Educational Psychology*, *44*(2), 247–264. https://doi.org/10.1080/01443410.2024.2329638

Berner, V. D., Seitz-Stein, K., Segerer, R., Oesterlen, E., & Niklas, F. (2022). 'Good' or 'well calculated'? Effects of feedback on performance and self-concept of 5- to 7-year-old children in math. *Educational Psychology*, *42*(3), 296–315. https://doi.org/10.1080/01443410.2021.2001790

Bock-Famulla, K., Berg, E., Girndt, A., Akko, D. P., Krause, M., & Schütz, J. (2023a). *Länderreport Frühkindliche Bildungssysteme 2023 - Bayern: Transparenz schaffen - Governance stärken* [Federal state report on early childhood education systems 2023 - Bavaria: Creating transparency - strengthening governance]. Verlag Bertelsmann Stiftung.

Bock-Famulla, K., Berg, E., Girndt, A., Akko, D. P., Krause, M., & Schütz, J. (2023b). *Länderreport Frühkindliche Bildungssysteme 2023 - Hamburg: Transparenz schaffen - Governance stärken* [Federal state report on early childhood education systems 2023 - Hamburg: Creating transparency - Strengthening governance]. Verlag Bertelsmann Stiftung.

Bower, C. A., Zimmermann, L., Verdine, B. N., Spiewak Toub, T., Hirsh-Pasek, K., & Michnick Golinkoff, R. (2025). What does play have to do with it? A concrete and digital spatial intervention with 3-year-olds predicts spatial and math learning. *Developmental Psychology*, *61*(3), 461–481. https://doi.org/10.1037/dev0001904

Cahoon, A., Gilmore, C., & Simms, V. (2021). Developmental pathways of early numerical skills during the preschool to school transition. *Learning and Instruction*, *75*, Article 101484. https://doi.org/10.1016/j.learninstruc.2021.101484

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Routledge. https://doi.org/10.4324/9780203771587

Cohrssen, C., & Niklas, F. (2019). Using mathematics games in preschool settings to support the development of children's numeracy skills. *International Journal of Early Years Education*, *27*(3), 322–339. https://doi.org/10.1080/09669760.2019.1629882

De Vita, C., Costa, H. M., Tomasetto, C., & Passolunghi, M. C. (2022). The contributions of working memory domains and processes to early mathematical knowledge between preschool and first grade. *Psychological Research*, *86*(2), 497–511. https://doi.org/10.1007/s00426-021-01496-4

Devlin, B. L., Zhang, H., Beliakoff, A., Miller-Cotto, D., Klein, A., & Jordan, N. C. (2024). Profiles of preschoolers' numerical abilities across quantity representations. *Canadian Journal of Experimental Psychology / Revue Canadienne De Psychologie Experimentale*, *79*(2), 221–227. https://doi.org/10.1037/cep0000339

Elofsson, J., Gustafson, S., Samuelsson, J., & Träff, U. (2016). Playing number board games supports 5-year-old children's early mathematical development. *The Journal of Mathematical Behavior*, *43*, 134–147. https://doi.org/10.1016/j.jmathb.2016.07.003

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power, 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. https://doi.org/10.3758/BF03193146

Fisher, K. R., Hirsh-Pasek, K., Newcombe, N., & Golinkoff, R. M. (2013). Taking shape: Supporting preschoolers' acquisition of geometric knowledge through guided play. *Child Development*, *84*(6), 1872–1878. https://doi.org/10.1111/cdev.12091

Fritz, A., Ehlert, A., & Balzer, L. (2013). Development of mathematical concepts as basis for an elaborated mathematical understanding. *South African Journal of Childhood Education*, *3*(1), 38–67. https://doi.org/10.4102/sajce.v3i1.31

Fritz, A., Ehlert, A., & Leutner, D. (2018). Arithmetische Konzepte aus kognitiv-entwicklungspsychologischer Sicht [Arithmetic concepts from a cognitive-developmental psychological perspective]. *Journal für Mathematik-Didaktik*, *39*(1), 7–41. https://doi.org/10.1007/s13138-018-0131-6

Fthenakis, W. E. (Ed.). (2009). *Natur-Wissen schaffen: Vol. 2. Frühe mathematische Bildung* [Early math education] (1st ed.). Bildungsverlag EINS.

Garon-Carrier, G., Boivin, M., Lemelin, J. P., Kovas, Y., Parent, S., Séguin, J. R., Vitaro, F., Tremblay, R. E., & Dionne, G. (2018). Early developmental trajectories of number knowledge and math achievement from 4 to 10 years: Low-persistent profile and early-life predictors. *Journal of School Psychology*, *68*, 84–98. https://doi.org/10.1016/j.jsp.2018.02.004

Garrote, A., & Opitz, E. M. (2021). Erfassung von mathematischen Kompetenzen im Vorschulalter mit MARKO-D: Erprobung des Tests MARKO-D an einer Schweizer Stichprobe und Überprüfung des Instruments für Messwiederholungen [Assessment of mathematical competencies in preschool age with MARKO-D]. *Diagnostica*, *67*(1), 13–23. https://doi.org/10.1026/0012-1924/a000258

Gashaj, V., Thaqi, Q., Mast, F. W., & Roebers, C. M. (2023). Foundations for future math achievement: Early numeracy, home learning environment, and the absence of math anxiety. *Trends in Neuroscience and Education*, *33*, Article 100217. https://doi.org/10.1016/j.tine.2023.100217

Gasteiger, H. (2015). Early mathematics in play situations: Continuity of learning. In B. Perry, A. MacDonald, & A. Gervasoni (Eds.), *Early mathematics learning and development. Mathematics and transition to school: International perspectives* (pp. 255–271). Springer. https://doi.org/10.1007/978-981-287-215-9_16

Gasteiger, H., & Moeller, K. (2021). Fostering early numerical competencies by playing conventional board games. *Journal of Experimental Child Psychology*, *204*, Article 105060. https://doi.org/10.1016/j.jecp.2020.105060

Gilligan, K. A., Thomas, M. S. C., & Farran, E. K. (2020). First demonstration of effective spatial training for near transfer to spatial performance and far transfer to a range of mathematics skills at 8 years. *Developmental Science*, *23*(4), Article e12909. https://doi.org/10.1111/desc.12909

Hassinger-Das, B., Jordan, N. C., & Dyson, N. (2015). Reading stories to learn math: Mathematics vocabulary instruction for children with early numeracy difficulties. *Elementary School Journal*, *116*(2), 242–246. https://doi.org/10.1086/683986

Hauser, B., Vogt, F., Stebler, R., & Rechsteiner, K. (2014). Förderung früher mathematischer Kompetenzen: Spielintegriert oder trainingsbasiert [Promotion of early mathematical competences: Game-integrated or training-based]. *Frühe Bildung*, *3*(3), 139–145. https://doi.org/10.1026/2191-9186/a000144

Hawes, Z. C. K., Gilligan-Lee, K. A., & Mix, K. S. (2022). Effects of spatial training on mathematics performance: A meta-analysis. *Developmental Psychology*, *58*(1), 112–137. https://doi.org/10.1037/dev0001281

Herzog, M., & Fritz, A. (2022). Entwicklungs- und spielbasierte Förderung früher arithmetischer Konzepte [Developmental and game-based promotion of early arithmetic concepts]. *Lernen und Lernstörungen*, *11*(1), 5–17. https://doi.org/10.1024/2235-0977/a000358

Hirsch, S., Lambert, K., Coppens, K., & Moeller, K. (2018). Basic numerical competences in large-scale assessment data: Structure and long-term relevance. *Journal of Experimental Child Psychology*, *167*, 32–48. https://doi.org/10.1016/j.jecp.2017.09.015

IBM Corp. (2023). *IBM SPSS Statistics* (Version 29.0.2.0) [Computer software]. https://www.ibm.com/de-de/products/spss-statistics

Jordan, N. C., Kaplan, D., Locuniak, M. N., & Ramineni, C. (2007). Predicting first-grade math achievement from developmental number sense trajectories. *Learning Disabilities Research and Practice*, *22*(1), 36–46. https://doi.org/10.1111/j.1540-5826.2007.00229.x

Jordan, N. C., Kaplan, D., Ramineni, C., & Locuniak, M. N. (2009). Early math matters: Kindergarten number competence and later mathematics outcomes. *Developmental Psychology*, *45*(3), 850–867. https://doi.org/10.1037/a0014939

Jörns, C., Schuchardt, K., Grube, D., & Mähler, C. (2014). Spielorientierte Förderung numerischer Kompetenzen im Vorschulalter und deren Eignung zur Prävention von Rechenschwierigeiten [Playful training of numerical skills in preschool for prevention of mathematical disability]. *Empirische Sonderpädagogik*, *3*, 243–259. https://doi.org/10.25656/01:9933

Jörns, C., Schuchardt, K., Mähler, C., & Grube, D. (2013). Alltagsintegrierte Förderung numerischer Kompetenzen im Kindergarten [Everyday integrated promotion of numerical competences in kindergarten]. *Frühe Bildung*, *2*(2), 84–91. https://doi.org/10.1026/2191-9186/a000088

Kiili, K., Moeller, K., & Ninaus, M. (2018). Evaluating the effectiveness of a game-based rational number training - in-game metrics as learning indicators. *Computers & Education*, *120*, 13–28. https://doi.org/10.1016/j.compedu.2018.01.012

Koponen, T., Aunola, K., & Nurmi, J. E. (2019). Verbal counting skill predicts later math performance and difficulties in middle school. *Contemporary Educational Psychology*, *59*, Article 101803. https://doi.org/10.1016/j.cedpsych.2019.101803

Krajewski, K. (2008). *Vorhersage von Rechenschwäche in der Grundschule* [Predicting dyscalculia in primary school] (2nd ed. Vol. 29). Dr. Kovač.

Krajewski, K., & Schneider, W. (2009). Early development of quantity to number-word linkage as a precursor of mathematical school achievement and mathematical difficulties: Findings from a four-year longitudinal study. *Learning and Instruction*, *19*(6), 513–526. https://doi.org/10.1016/j.learninstruc.2008.10.002

Lange, A. A., Brenneman, K., & Sareh, N. (2020). Using number games to support mathematical learning in preschool and home environments. *Early Education and Development*, *32*(3), 459–479. https://doi.org/10.1080/10409289.2020.1778386

Laski, E. V., & Siegler, R. S. (2014). Learning from number board games: You learn what you encode. *Developmental Psychology*, *50*(3), 853–864. https://doi.org/10.1037/a0034321

Lin, C. H. (2022). Developing mental number line games to improve young children's number knowledge and basic arithmetic skills. *Journal of Experimental Child Psychology*, *222*, Article 105479. https://doi.org/10.1016/j.jecp.2022.105479

Miller, K. F., & Paredes, D. R. (1990). Starting to add worse: Effects of learning to multiply on children's addition. *Cognition*, *37*(3), 213–242. https://doi.org/10.1016/0010-0277(90)90046-M

Mix, K. S., Levine, S. C., Cheng, Y. L., Stockton, J. D., & Bower, C. (2021). Effects of spatial training on mathematics in first and sixth grade children. *Journal of Educational Psychology*, *113*(2), 304–314. https://doi.org/10.1037/edu0000494

Morgan, P. L., Farkas, G., & Wu, Q. (2011). Kindergarten children's growth trajectories in reading and mathematics: Who falls increasingly behind? *Journal of Learning Disabilities*, *44*(5), 472–488. https://doi.org/10.1177/0022219411414010

National Association for the Education of Young Children & National Council of Teachers of Mathematics. (2002). *Early childhood mathematics: Promoting good beginnings*. (Joint position statement. Adopted in 2002. Updated in 2010).

Nesbitt, K. T., Blinkoff, E., Golinkoff, R. M., & Hirsh-Pasek, K. (2023). Making schools work: An equation for active playful learning. *Theory into Practice*, *62*(2), 141–154. https://doi.org/10.1080/00405841.2023.2202136

Niklas, F., Birtwistle, E., Mues, A., & Wirth, A. (2025). Learning apps at home prepare children for school. *Child Development*, *96*(2), 577–590. https://doi.org/10.1111/cdev.14184

Nogues, C. P., & Dorneles, B. V. (2021). Systematic review on the precursors of initial mathematical performance. *International Journal of Educational Research Open*, *2*, Article 100035. https://doi.org/10.1016/j.ijedro.2021.100035

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2018). The effectiveness of computer and tablet assisted intervention in early childhood students' understanding of numbers. An empirical study conducted in Greece. *Education and Information Technologies*, *23*(5), 1849–1871. https://doi.org/10.1007/s10639-018-9693-7

Park, S., & Esposito, A. G. (2022). Rational number conceptualization predicts mathematics achievement: Quantity matters. *Cognitive Development*, *63*, Article 101195. https://doi.org/10.1016/j.cogdev.2022.101195

Purpura, D. J., O'Rear, C. D., Ellis, A., Logan, J. A. R., Westerberg, L., Ehrman, P., King, Y. A., Vander Tuin, M., Nordgren, I., Anderson, K., Cosso, J., Zippert, E., Napoli, A. R., Hornburg, C. B., Schmitt, S. A., & Dobbs-Oates, J. (2024). Unique and combined effects of quantitative mathematical language and numeracy instruction within a picture book intervention: A registered report. *Journal of Educational Psychology*, *116*(1), 1–19. https://doi.org/10.1037/edu0000820

Purpura, D. J., Schmitt, S. A., Napoli, A. R., Dobbs-Oates, J., King, Y. A., Hornburg, C. B., Westerberg, L., Borriello, G. A., Bryant, L. M., Anaya, L. Y., Kung, M., Litkowski, E., Lin, J., & Rolan, E. (2021). Engaging caregivers and children in picture books: A family-implemented mathematical language intervention. *Journal of Educational Psychology*, *113*(7), 1338–1353. https://doi.org/10.1037/edu0000662

Ramani, G. B., Daubert, E. N., Lin, G. C., Kamarsu, S., Wodzinski, A., & Jaeggi, S. M. (2020). Racing dragons and remembering aliens: Benefits of playing number and working memory games on kindergartners' numerical knowledge. *Developmental Science*, *23*(4), Article e12908. https://doi.org/10.1111/desc.12908

Ramani, G. B., Jaeggi, S. M., Daubert, E. N., & Buschkuehl, M. (2017). Domain-specific and domain-general training to improve kindergarten children's mathematics. *Journal of Numerical Cognition*, *3*(2), 468–495. https://doi.org/10.5964/jnc.v3i2.31

Ramani, G. B., & Scalise, N. R. (2020). It's more than just fun and games: Play-based mathematics activities for head start families. *Early Childhood Research Quarterly*, *50*, 78–89. https://doi.org/10.1016/j.ecresq.2018.07.011

Ramani, G. B., & Siegler, R. S. (2008). Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development*, *79*(2), 375–394. https://doi.org/10.1111/j.1467-8624.2007.01131.x

Ramani, G. B., Siegler, R. S., & Hitti, A. (2012). Taking it to the classroom: Number board games as a small group learning activity. *Journal of Educational Psychology*, *104*(3), 661–672. https://doi.org/10.1037/a0028995

Resnick, L. B. (1983). A developmental theory of number understanding. In H. P. Ginsburg (Ed.), *The development of mathematical thinking* (pp. 109–151). Academic Press, Inc. https://eric.ed.gov/?id=ed251328

Ricken, G., Fritz, A., & Balzer, L. (2013). *Mathematik- und Rechenkonzepte im Vorschulalter - Diagnose (MARKO-D) [Preschool mathematics and numeracy concepts - diagnosis (MARKO-D)]*. Hogrefe.

Scalise, N. R., DePascale, M., Tavassolie, N., McCown, C., & Ramani, G. B. (2022). Deal me in: Playing cards in the home to learn math. *Education Sciences*, *12*(3), 190. https://doi.org/10.3390/educsci12030190

Seeger, D., Holodynski, M., & Roth, M. (2018). BIKO-Mathekiste: Spielbasierte Förderung für 4- bis 6-jährige Kinder mit einem Entwicklungsrisiko im Bereich numerischer Basiskompetenz [BIKO math box: Play-based support for 4- to 6-year-old children with a developmental risk in the area of basic numerical skills]. *Frühe Bildung*, *7*(3), 135–143. https://doi.org/10.1026/2191-9186/a000380

Siegler, R. S. (1998). *Emerging minds: The process of change in children's thinking*. Oxford University Press.

Siegler, R. S., & Booth, J. L. (2004). Development of numerical estimation in young children. *Child Development*, *75*(2), 428–444. https://doi.org/10.1111/j.1467-8624.2004.00684.x

Siegler, R. S., & Ramani, G. B. (2009). Playing linear number board games-but not circular ones-improves low-income preschoolers' numerical understanding. *Journal of Educational Psychology*, *101*(3), 545–560. https://doi.org/10.1037/a0014239

Skene, K., O'Farrelly, C. M., Byrne, E. M., Kirby, N., Stevens, E. C., & Ramchandani, P. G. (2022). Can guidance during play enhance children's learning and development in educational contexts? A systematic review and meta-analysis. *Child Development*, *93*(4), 1162–1180. https://doi.org/10.1111/cdev.13730

Skillen, J., Berner, V. D., Ricken, G., & Seitz-Stein, K. (2018). Förderung basisnumerischer Kompetenzen mit einem regelbasierten Spiel im Einzel- und Gruppensetting [Promoting basic numerical skills with a rule-based game in individual and group settings]. *Frühe Bildung*, *7*(3), 144–151. https://doi.org/10.1026/2191-9186/a000381

Skillen, J., Berner, V. D., & Seitz-Stein, K. (2018). The rule counts! Acquisition of mathematical competencies with a number board game. *Journal of Educational Research*, *111*(5), 554–563. https://doi.org/10.1080/00220671.2017.1313187

Stern, E. (2009). The development of mathematical competencies: Sources of individual differences and their developmental trajectories. In W. Schneider & M. Bullock (Eds.), *Human development from early childhood to early adulthood* (pp. 221–237). Taylor and Francis. https://doi.org/10.4324/9780203888544-15

Träff, U., Olsson, L., Skagerlund, K., & Östergren, R. (2020). Kindergarten domain-specific and domain-general cognitive precursors of hierarchical mathematical development: A longitudinal study. *Journal of Educational Psychology*, *112*(1), 93–109. https://doi.org/10.1037/edu0000369

Träff, U., Skagerlund, K., Östergren, R., & Skagenholt, M. (2023). The importance of domain-specific number abilities and domain-general cognitive abilities for early arithmetic achievement and development. *British Journal of Educational Psychology*, *93*(3), 825–841. https://doi.org/10.1111/bjep.12599

Vogt, F., Hauser, B., Stebler, R., Rechsteiner, K., & Urech, C. (2018). Learning through play - pedagogy and learning outcomes in early childhood mathematics. *European Early Childhood Education Research Journal*, *26*(4), 589–603. https://doi.org/10.1080/1350293X.2018.1487160

Watts, T. W., Duncan, G. J., Siegler, R. S., & Davis-Kean, P. E. (2014). What's past is prologue: Relations between early mathematics knowledge and high school achievement. *Educational Researcher*, *43*(7), 352–360. https://doi.org/10.3102/0013189X14553660

Weisberg, D. S., Hirsh-Pasek, K., & Golinkoff, R. M. (2013). Guided play: Where curricular goals meet a playful pedagogy. *Mind, Brain, and Education*, *7*(2), 104–112. https://doi.org/10.1111/mbe.12015

Whyte, J. C., & Bull, R. (2008). Number games, magnitude representation, and basic number skills in preschoolers. *Developmental Psychology*, *44*(2), 588–596. https://doi.org/10.1037/0012-1649.44.2.588

Young-Loveridge, J. M. (2004). Effects on early numeracy of a program using number books and games. *Early Childhood Research Quarterly*, *19*(1), 82–98. https://doi.org/10.1016/j.ecresq.2004.01.001

Zhang, X., & Gunderson, E. A. (2025). The transfer effect of mental rotation training on arithmetic skill: The role of state anxiety and arithmetic strategy use. *Developmental Psychology*, *62*(9), 1834–1846. https://doi.org/10.1037/dev0002040

Zosh, J. M., Hirsh-Pasek, K., Hopkins, E. J., Jensen, H., Liu, C., Neale, D., Solis, S. L., & Whitebread, D. (2018). Accessing the inaccessible: Redefining play as a spectrum. *Frontiers in Psychology*, *9*, Article 1124. https://doi.org/10.3389/fpsyg.2018.01124