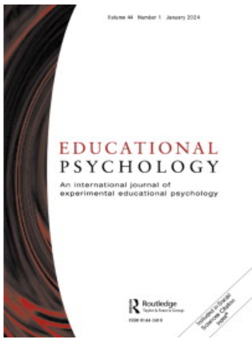

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Play-integrated fostering of basic mathematical skills: findings of two experiments

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ABSTRACT

Empirical research highlights the benefits for the development of children's mathematical competencies when they play linear number board games with dice and receive feedback. We, therefore, investigated mathematical competencies in two training studies with six sessions and a 3×2 design. The sample in the first experiment consisted of $N = 79$ German 5- to 7-year-old preschoolers and in the second of $N = 64$ German 6- to 8-year-old primary school students. Participants either belonged to a passive control group or played the board game House of Numbers up to number 20 (HoN-20). Some members of the HoN-20 group received specific feedback (e.g. 'well calculated'), while the remaining children received unspecific feedback (e.g. 'good'). Pre-posttest comparisons pointed to diverse effects: Playing the HoN-20 game and receiving feedback led to significantly greater gains in different levels of acquisition of basic arithmetic skills.

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Experiments; development of mathematical competencies; feedback; linear board game; House of Numbers; children

Introduction

It is undisputed that children's basic arithmetic skills in preschool predict children's later maths performance (Duncan et al., 2007; Lange et al., 2021; Outhwaite et al., 2019; Skillen et al., 2017). Consequently, there is a need to foster arithmetic skills such as counting, reading numbers, addition or comparing quantities, in preschool and early school years to enable all children to acquire these competencies. However, previous research on basic arithmetic skills has mostly looked at the impact of beneficial effects on general mathematical competencies (Hauser et al., 2014; Jörns et al., 2017; Jörns et al., 2014).

The current study, therefore, evaluated the potential effects of play-integrated mathematical learning on different levels of mathematical development (Fritz et al., 2013). This study was an extension to the study by Berner and colleagues (2022) that

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examined the effects of the play-based mathematical fostering of children's learning motivation and learning performance. Here, we focused on differentiated mathematical learning performance based on the different levels of a cognitive developmental model (Fritz et al., 2014). In addition, we aimed to replicate the findings from a preschool sample in primary school.

Mathematical development during childhood

Children start acquiring mathematical skills long before they go to school (Fritz et al., 2013; Fuson, 1988; Langhorst et al., 2013). In German federal states, mathematical learning is anchored in preschool curricula (Gasteiger, 2012). Some of these curricula are based on theoretical models which describe and explain the development of mathematical skills (Bayerisches Staatsministerium für Familie, Arbeit und Soziales & Staatsinstitut für Frühpädagogik, 2019). One of these models is the *cognitive developmental model* (CDM) developed by Fritz and colleagues (Fritz et al., 2014; Fritz et al., 2013; Fritz et al., 2018; Fritz & Ricken, 2008). This model distinguishes between six levels in the development and acquisition of arithmetic skills by 4- to 8-year-old children (see Figure 1).

It is based on various theoretical assumptions (e.g. Piaget, overlapping waves, etc.) and empirical evidence (Ehlert & Fritz, 2013; Fritz et al., 2013; Fritz et al., 2018; Siegler & Alibali, 2005).

At the first level (*count number*), usually at the age of two to three years, children begin to develop a number-words line. During this process children learn number words without linking them to their specific meaning (Ehlert & Fritz, 2013). In addition, children start to understand the one-to-one correspondence, i.e. that number words are linked to quantities of objects. The second level (*mental number*) involves developing the ordinal concept. Here, the representation of number changes to a mental representation. Children begin to construct a mental number line.

Another key step is achieved at the third level – the acquisition of the cardinal number concept (*cardinality and decomposability*). At this point, children are able to

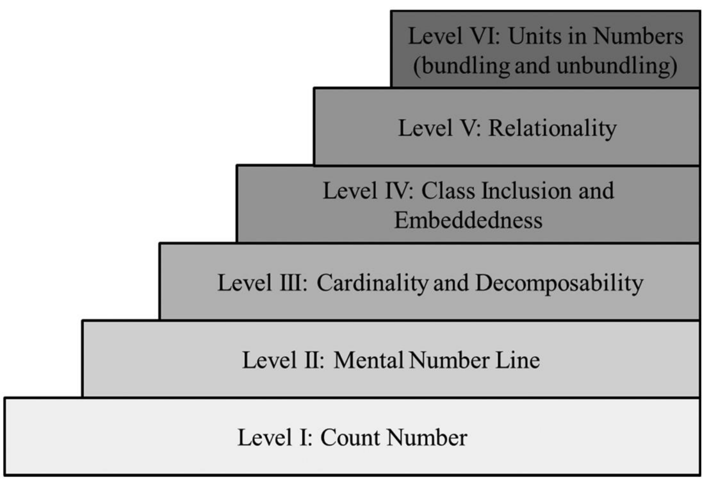

Figure 1. Cognitive developmental model (Fritz et al., 2014).

grasp the number word line as a sequence of increasing cardinality (Langhorst et al., 2013). Once they reach the fourth level (*class inclusion and embeddedness*), children begin to understand the relations of numbers (Fritz et al., 2014). Based on the part-whole concept, children are able to understand that numbers can be decomposed into partial quantities. At level five (*relationality*) children comprehend that the distance between two adjoining numbers is the same. In addition, they also understand that each number word is a sequence word and a sequence of cardinal units (Fritz et al., 2014). The assumption is that preschoolers initially acquire these different arithmetical concepts of levels 1 to 5 only in the number range from 1 to 20 (Fritz et al., 2018). At level six (*units in numbers*) children learn bundling a number into partial segments (e.g. 8:2) and unbundling numbers. They understand that a number is a segment on the number line which can be flexibly differentiated into partial quantities of the same size (Fritz et al., 2013). Moreover, children, who acquire these competencies, can do calculations with numbers up to 100 and attend primary school.

Research has demonstrated that such mathematical skills and knowledge are important for the further development of children's mathematical competencies (Duncan et al., 2007; Lange et al., 2021). However, young children differ in terms of these skills (Elofsson et al., 2016; Gasteiger, 2012; Gasteiger & Moeller, 2021; Lange et al., 2021; Outhwaite et al., 2019). Children who have problems acquiring basic arithmetic skills at preschool are often prone to learning difficulties at school (Ehlert & Fritz, 2013). Consequently, fostering mathematical development in (pre)school is essential.

Fostering basic arithmetical skills with linear board games with due consideration of the CDM

In recent years, a wealth of evidence has confirmed the benefits of training in arithmetical skills for preschool children (Gasteiger, 2012; Hauser et al., 2014; Ramani & Siegler, 2008). Some of these training programs are based on theories of mathematical development (e.g. Jörns et al., 2014; Skillen et al., 2017). Some of them use board games (Gasteiger & Moeller, 2021; Hauser et al., 2014; Jörns et al., 2014; Laski & Siegler, 2014; Ramani & Siegler, 2008; Skillen et al., 2017).

Board game-based learning programs are often motivational and include the unpredictable and variable progression and outcome of a dice game and informal learning activities for selected mathematical skills (Gasteiger, 2012; Hauser et al., 2014; Ramani et al., 2012). Moreover, playing board games gives children an opportunity to grasp basic arithmetical concepts (Gasteiger, 2012) such as reading numbers on dice. This, in turn, fosters an understanding of the one-to-one correspondence. When children play with dice, they learn that number words are linked to quantities of objects. These aspects are central for the counting process at level 1 of the developmental model for the acquisition of numeracy (CDM; Fritz et al., 2013).

When numbers are written on a board such as in Chutes and Ladders (Milton Bradley Company, 1978), children read and count them when they move their token forward. Through seeing the arrangement of numbers on the playing board, children begin to realise that the number word line has a fixed order and they can develop their mental number line (Langhorst et al., 2013; level 2). In addition, children can acquire an initial understanding of cardinality and division into parts while playing the game (level 3). If children count all steps on a board game (e.g. 4), they can reason that each step is assigned a number word and that all counters together will add up to the total number of steps with the attribute four. Consequently, children have a chance to understand the number 4 as a quantity and that it can be decomposed into smaller numbers (Fritz et al., 2013).

In addition, board games may also support the acquisition of the part-part-whole concept (Gasteiger, 2012; level 4). For instance, when a child rolls the dice and gets a 5, and another child rolls the dice twice and gets a 2 and a 3, children can understand that the 5 can be decomposed into a 2 and a 3 (Fritz et al., 2013).

Board games may also include variations of rules or special fields or tasks (Berner et al., 2022; Laski & Siegler, 2014; Skillen et al., 2017). For instance, when an educator asks a child 'Which game figure has to take more steps to reach the goal? How many more steps are there?' (Langhorst et al., 2013) during board game play, mathematical skills are put into practice. To solve such a task, the child needs to have grasped the relational number concept (level 5) and to have understood both the cardinality and ordinality of numbers as well as the relationship between both concepts (Fritz et al., 2013).

Recent research on board game-based learning approaches showed beneficial effects on mathematical skills (Jörns et al., 2014; Laski & Siegler, 2014; Skillen et al., 2017) and comparable results to standard training programs (Hauser et al., 2014; Skillen et al., 2017). In addition, further results suggested that playing linear board games improved children's ability to acquire higher arithmetic skills (Elofsson et al., 2016; Siegler & Ramani, 2009). It can, therefore, be assumed that playing board games may boost arithmetic skills at higher levels based on the CDM (Fritz et al., 2018; Ricken et al., 2013).

To date, very few studies have reported beneficial effects based on specific levels of developmental models of mathematical development (Jörns et al., 2014; Skillen et al., 2017). Most of the studies reported results of general mathematical skills by using a total score (Elofsson et al., 2016; Hauser et al., 2014). Others focused on specific aspects of mathematical skills such as, for example, counting or number line estimation (Jörns et al., 2013; Laski & Siegler, 2014; Ramani et al., 2012). More research is needed to investigate the beneficial effects of playing a mathematical linear board game at each level of the CDM (Ricken et al., 2013) and in different educational settings.

Fostering basic arithmetical skills by using feedback

The effectiveness of game-based learning also depends on the methods used, for instance feedback (Berner et al., 2022; Johnson et al., 2017). In educational contexts, feedback is defined as information provided to children regarding their understanding and/or performance (Hattie & Timperley, 2007). Prior research identified beneficial effects of feedback on children's maths performance in traditional learning settings (Fyfe & Brown, 2018; Kluger & DeNisi, 1996; Narciss & Huth, 2006) and on student's performance in game-based settings (Freitas et al., 2023; Johnson et al., 2017).

However, these effects depended on the type of feedback (e.g. positive, implicit, internal, praise; see Berner et al., 2022; Harks et al., 2014; Kluger & DeNisi, 1996), on the format of feedback (i.e. visual, auditory/spoken), on the timing of feedback, and on the adaptation of feedback to individual differences (Freitas et al., 2023; Johnson et al., 2017). In this study, we focused on two types of feedback: unspecific and specific feedback in game-played learning settings. Unspecific feedback is a simple type of feedback which is thought to foster developing mathematical skills via praise or a simple confirmation of children's maths results (i.e. 'correct'). In contrast, specific feedback is considered to be beneficial for the development of mathematical skills by providing elaborated information about children's learning processes (Johnson et al., 2017) and maths performance (Berner et al., 2022). Findings on feedback in science or military game-based learning settings showed that especially students, who received specific feedback, recorded a greater increase in performance (Johnson et al., 2017). According to Freitas and colleagues (2023), it seems that specific feedback in a game-played learning setting motivated students and enabled them to adapt their behaviour. However, it remains unclear, whether these findings can also be transferred to mathematics education in preschool and primary school. Furthermore, there is a lack of studies investigating the influence of specific and unspecific feedback in pre- and primary school game-based learning settings, while considering the different levels of the CDM (Johnson et al., 2017; Ricken et al., 2013).

The present study

In the present study, we examined the potentially beneficial effects of linear board games and the potential effects of varying feedback on different levels of the CDM (Fritz et al., 2013). Based on theoretical assumptions and prior empirical findings presented above, the following hypotheses were tested in two experiments:

1. Children, who have played the linear board game and received feedback, show a greater gain in their arithmetical skills than children in the control group.
2. Children, who have played the linear board game and have received feedback, acquire mathematical skills and concepts of higher levels, compared to those who haven't played the linear board game.
3. The gain in arithmetical skills of children with specific feedback is greater than the gain of children in the unspecific feedback-group.

The age of the sample differed in the experiments. In experiment 1 we examined children of kindergarten age. In experiment 2 we examined children of primary school age.

Experiment 1

Method

Participants

The sample consisted of $N = 88$ children (48 girls) ranging in age from 5 to 7 years, $M_{age} = 5.99$ years ($SD_{age} = 0.39$). The children were recruited from five state or church-run kindergartens in south Germany (Bavaria) in the spring of 2018. Ten children were excluded from data analysis because they were absent for extended periods or had insufficient knowledge of the German language. Due to the small sample size, a sensitivity analysis was conducted using G*Power version 3.1.4 (Faul et al., 2009) to compute the required effect size. With a significance criterion of $\alpha = 0.05$ and power $= 0.90$, the effect size was Cohen's $f = 0.20$ (converted $\eta_p^2 = .04$). Informed written parental consent was obtained for all participants. Children were randomly assigned by preschool or preschool group to the specific feedback condition, the unspecific feedback condition, or the control group. The specific feedback condition included $n = 24$ children ($M_{age} = 6.04$ years, $SD_{age} = 0.45$ years, 16 girls). The unspecific feedback condition included $n = 23$ children ($M_{age} = 6.02$ years, $SD_{age} = 0.41$ years, 12 girls). The control group condition included $n = 31$ children ($M_{age} = 5.93$ years, $SD_{age} = 0.32$ years, 16 girls).

Overview of procedure and design

The experiment encompassed eight sessions. For the pre- and posttest (sessions 1 and 8) each of the children met individually with a research assistant and participated in activities involving basic mathematical skills. During sessions 2–7, children in the feedback conditions played the linear board game the *House of Numbers up to number 20* (HoN, 20; Berner et al., 2022), which took 10 to 20 minutes per session. The children in the control group took part in the usual kindergarten program. A 3 (unspecific feedback condition, specific feedback condition and control group) × 2 (pretest and posttest) design was used (see Figure 2).

Materials and procedure in pre- and posttest sessions

To measure the basic arithmetic skills at pre- and posttest, the children were assessed using 28 mathematical items adapted from the test *Mathematik- und Rechenkonzepte im Vorschulalter – Diagnose* (MARKO-D; Ricken et al., 2013), in the same order for both the pre- and posttests. Both sessions lasted around 20 minutes. As the majority of

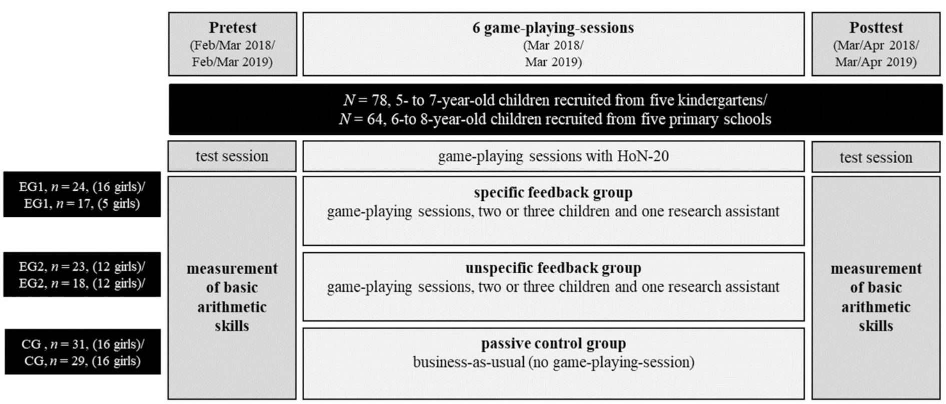

Figure 2. Design of the experiments 1 and 2. *Note.* HoN-20 = House of Numbers up to number 20. EG1 = specific feedback group. EG2 = unspecific feedback group. CG = passive control group. Notices of experiment 1/notices of experiment 2.

preschoolers only count up to 20, only levels 1 to 5 were recorded, as in the MARKO-D (Ricken et al., 2013). The different levels were Rasch scaled. The reliability of all mathematical tasks was acceptable with $\alpha_{t1/t2} = .79/.79$.

Level 1: Based on the CDM of acquisition of basic arithmetic concepts by Fritz and colleagues (Fritz et al., 2014), seven items each were used to measure level 1 (*Count Number*, e.g. 'Which number did you roll with the dice?'; $\alpha_{t1/t2} = .42/.10$) and level 2 (*Mental Number*, e.g. 'Which number comes after ten?'; $\alpha_{t1/t2} = .49/.54$). Level 3 (*Cardinality and Decomposability*) was operationalised with eight items (e.g. 'How many doors are five doors and four doors together?'; $\alpha_{t1/t2} = .31/.43$). Finally, two items were used to measure level 4 (*Class inclusion and Embeddedness*, e.g. 'How many are ten chips? Please give me exactly ten chips, but two of the chips must be blue.'; $\alpha_{t1/t2} = .50/.47$) and four items measured Level 5 (*Relationality*, e.g. 'And how much more is that?'; $\alpha_{t1/t2} = .63/.71$).

Material and procedure of the game-playing sessions

The HoN-20 (see Figure 3) was used in all the game-playing sessions. It has three special fields with mathematical tasks on the board and a 10-sided dice, labelled 1 through 5 (for more details, see Berner et al., 2022). In each of the six game-playing sessions, children played the HoN-20 in groups (2–3 children) with a research assistant using the count-on rule (Laski & Siegler, 2014).

At the start of the game-playing session, the experimenter presented the HoN-20 board game and explained the rules of the game to the children. If children had

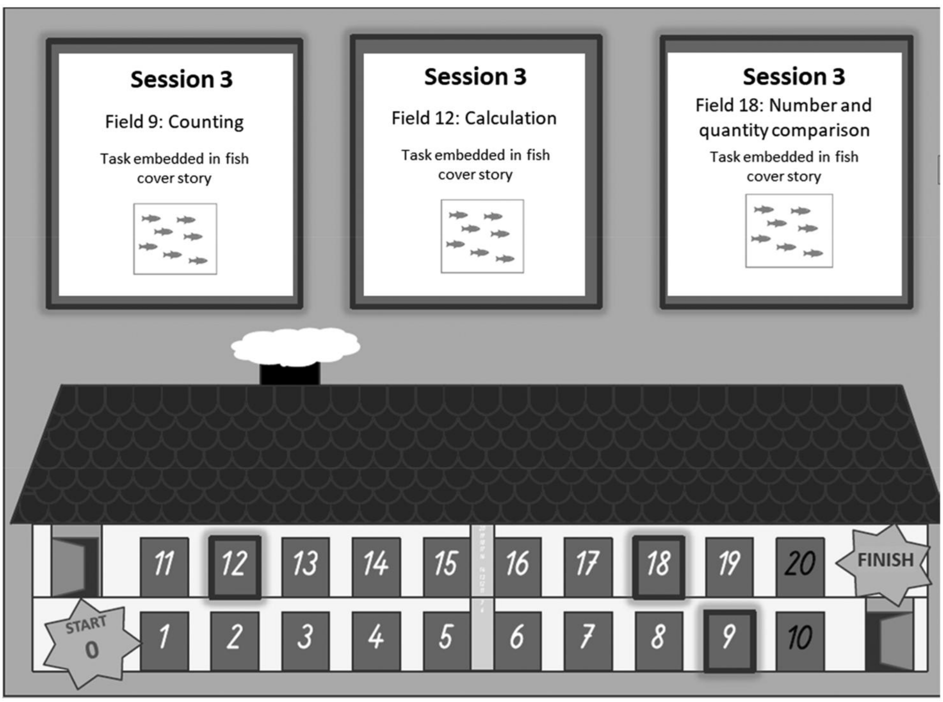

Figure 3. Linear board game: House of Numbers up to number 20 (HoN-20; see Berner et al., 2022, p. 302).

difficulties in counting or solving special mathematical tasks, the research assistant helped them. When it was the research assistant's turn, all of the children helped count or solve his/her special mathematical tasks. The special mathematical tasks matched levels 1, 2, and 3 of the CDM of acquisition of basic arithmetic concepts by Fritz and colleagues (Fritz et al., 2014). During the game-playing sessions, the children in the experimental groups received specific or unspecific feedback (for more details see Berner et al., 2022). The game sessions ended when all players had reached the end field.

Data analysis

Descriptive statistics are presented separately for each group in Table 1. Using Pillai's trace, the results of a multivariate analysis of variance (MANOVA) demonstrated that there were no significant differences between institutions in terms of age, gender, and basic arithmetic skills at t1, $V = 0.09$, $F(6,\ 148) = 1.19$, $p = .317$. In addition, we conducted 3×2 mixed-model analyses of repeated measures (ANOVA) with a between-subject factor group (specific, unspecific and control group) and the within-subject factor of change across time (pre- and posttest). In depth analyses were conducted in order to identify potentially beneficial effects at different levels (1–5) of the CDM.

Results and discussion

Table 1 gives the means and standard deviations at pre- and posttest for all conditions. At pretest, the means of mathematical performance were quite similar in all three groups.

3 (group [specific feedback group, unspecific feedback group, control group]) $\times$ 2 session [pre-, posttest]) repeated measures ANOVAs were conducted on the overall score of basic arithmetic skills and on all five levels. The results of these ANOVAs and further results are presented in Tables 2 and 3.

Table 1. Descriptive statistics for each group in experiment 1.

			Specific feedback group		Unspecific feedback group		Control group	
	Min.	*Max.*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pretest								
Total score	7.00	22.00	14.17	4.16	12.74	4.33	15.16	3.27
Level 1	4.00	7.00	6.21	1.02	6.04	1.02	6.77	0.56
Level 2	0.00	4.00	2.92	1.02	2.48	1.24	2.77	1.23
Level 3	1.00	5.00	2.96	1.20	2.52	1.47	3.45	0.85
Level 4	0.00	3.00	1.21	0.98	1.09	1.04	1.39	1.09
Level 5	0.00	4.00	0.88	1.19	0.61	1.08	0.77	1.02
Posttest								
Total score	8.00	23.00	17.58	3.73	15.04	3.60	15.77	3.54
Level 1	4.00	7.00	6.58	0.58	6.43	0.79	6.71	0.53
Level 2	0.00	4.00	3.21	0.93	2.60	1.16	3.16	1.13
Level 3	0.00	5.00	4.21	1.22	3.73	1.14	3.61	1.15
Level 4	0.00	3.00	2.00	0.98	1.43	1.04	1.68	1.05
Level 5	0.00	4.00	1.58	1.53	0.83	1.15	0.61	0.92

Table 2. Results of repeated measures ANOVA in experiment 1, total scores, and levels 1–2 of mathematical competencies.

	Total score				Level 1				Level 2			
Effect	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2
Time (T)	**42.25**	**(1,75)**	**.001**	**.36**	3.89	(1,75)	.052	.05	**5.90**	**(1,75)**	**.018**	**.07**
Groups (G)	2.17	(2,75)	.122	.06	**5.95**	**(2,75)**	**.004**	**.12**	1.76	(2,75)	.179	.05
T × G	**6.77**	**(2,75)**	**.002**	**.15**	1.73	(2,75)	.184	.04	0.46	(2,75)	.632	.01
Further results:												
EG1 (T1-T2)	**32.91**	**(1,23)**	**.000**	**.59**	2.81	(1,23)	.107	.11	2.24	(1,23)	.089	.09
EG2 (T1-T2)	**11.44**	**(1,22)**	**.003**	**.34**	2.18	(1,22)	.150	.08	0.42	(1,22)	.525	.20
CG (T1-T2)	1.97	(1,30)	.171	.06	0.22	(1,30)	.645	.01	**4.75**	**(1,30)**	**.037**	**.14**
Performance T1	2.75	(2,75)	.083	.08	**5.41**	**(2,75)**	**.006**	**.13**	0.86	(2,75)	.428	.02
Performance T2	**3.57**	**(2,76)**	**.033**	**.09**	1.08	(2,76)	.344	.03	2.90	(2,76)	.061	.07

Note. EG1 = experimental group with specific feedback. EG2 = experimental group with unspecific feedback. CG = control group. T1 = pretest. T2 = posttest. Bold font indicates statistical significance.

Table 3. Results of repeated measures ANOVA in experiment 1 levels 3–5 of mathematical competencies.

	Level 3				Level 4				Level 5			
Effect	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2
Time (T)	**35.43**	**(1,75)**	**.000**	**.32**	**18.25**	**(1,75)**	**.000**	**.20**	**6.32**	**(1,75)**	**.014**	**.08**
Groups (G)	1.56	(2,75)	.217	.04	0.94	(2,75)	.394	.03	2.05	(2,75)	.136	.05
T × G	**6.47**	**(2,75)**	**.003**	**.15**	2.00	(2,75)	.142	.03	**6.50**	**(2,75)**	**.003**	**.15**
Further results:												
EG1 (T1-T2)	**19.38**	**(1,23)**	**.000**	**.46**	**13.33**	**(1,23)**	**.001**	**.37**	**10.27**	**(1,23)**	**.004**	**.31**
EG2 (T1-T2)	**19.78**	**(1,22)**	**.000**	**.47**	**4.02**	**(1,22)**	**.057**	**.16**	1.20	(1,22)	.285	.05
CG (T1-T2)	0.57	(1,30)	.455	.02	2.58	(1,30)	.119	.08	1.98	(1,30)	.169	.06
Performance T1	**4.24**	**(2,75)**	**.018**	**.10**	0.57	(2,75)	.568	.02	0.36	(2,75)	.702	.01
Performance T2	2.00	(2,76)	.143	.50	2.22	(2,76)	.120	.06	**4.78**	**(2,76)**	**.011**	**.11**

Note. EG1 = experimental group with specific feedback. EG2 = experimental group with unspecific feedback. CG = control group. T1 = pretest. T2 = posttest. Bold font indicates statistical significance.

Our findings showed that children's mathematical performance (total score) varied over time, but not by group. The interaction of both factors was significant and indicated that children's mathematical performance (total score) differed over time depending on the condition. Here, both experimental groups showed a significantly greater mathematical performance (total score) compared to their performance at pretest. In addition, these children chalked up a higher overall score after training than the children in the control group.

At level 1, a significant main effect of group was observed. Groups differed on level 1 at pretest. However, no differences in total scores of mathematical performances were found at posttest. Moreover, neither a main effect of time nor a group by time interaction was observed.

A main effect of time and an effect for the control group were shown at level 2. In general, the participating children gained significantly more mathematical knowledge at level 2, and here, especially children in the control group showed a major gain.

At level 3, the repeated measures ANOVA identified a significant main effect of time, but not of group, while the interaction of time and group was significant. Here, children in both experimental groups showed a significantly greater gain in their development of mathematical knowledge (level 3) compared to the control group.

The results for level 4 indicated that, in general, all children significantly gained new knowledge between the pre- and posttests independent of the condition. However, this gain was only significant for the intervention group with specific feedback. The repeated measures ANOVA for level 5 showed that children's mathematical performance improved significantly from the pre- to posttest assessments and that, in this case, children in EG1 showed a significantly greater improvement compared to children in the EG2 and the control group. In comparison, no significant change was observed for children in the EG2 and the control group.

To summarise, the results of experiment 1 showed that children who played the linear board game and received feedback, showed significantly greater gains in different levels of basic arithmetic skills compared to children in the passive control group. Furthermore, children of EG1 presented the steepest slopes at level 5. To test how effective the training was for elementary school-aged children, too, and to determine whether the training program had effects at higher than trained levels, we performed a second experiment using a similar training program for first graders.

Experiment 2

Method

Participants

The 67 first graders participating in the second study were recruited from five German state primary schools in 2019. Parental consent was obtained for all participating children. After the pretest, children were randomly assigned to one of the three groups. Data of three children were excluded from the experiment. Due to the small sample size, a sensitivity analysis was conducted using G*Power version 3.1.4 (Faul et al., 2009) to compute the required effect size. With a significance criterion of $\alpha = 0.05$ and power $= 0.90$, the effect size was Cohen's $f = 0.23$ (converted $\eta_p^2 = .05$). The experimental group with specific feedback (EG1) included 17 children ($M_{age} = 6.93$, $SD_{age} = 0.32$, 5 girls), the experimental group with unspecific feedback (EG2) included 18 children ($M_{age} = 6.90$, $SD_{age} = 0.47$; 12 girls). The control group (CG) included 29 children (16 girls). Due to missing data, age could only be specified for 12 children in the control group ($M_{age} = 7.19$, $SD_{age} = 0.47$).

Overview of procedure and design

The entire procedure and design were identical to experiment 1, except for the special mathematical tasks in the game-playing sessions.

Materials and procedure in pre- and posttest sessions

The materials were similar to those used in the first experiment. Instead of the 28 mathematical items from MARKO-D, the established *Mathematik- und Rechenkonzepte bei Kindern der ersten Klassenstufe – Diagnose* (MARKO-D1+; (Fritz et al., 2017) was used to measure basic arithmetic skills in the first grade of primary school. The test included 48 items at levels 1 to 6 and was presented to children in the same order at pre- and posttest. Both sessions lasted about 30 minutes. The reliability of all mathematical tasks of the MARKO-D1+ (Fritz et al., 2017) was good with $\alpha_{t1/t2} = .89/.89$. The

MARKO-D1+ (Fritz et al., 2017) encompassed levels 1–6 of the CDM (Fritz et al., 2014) and the levels were Rasch scaled. Eight items were used to measure levels 1/2 (*Count Number* and *Mental Number*, e.g. 'Which number comes after ten?'; $\alpha_{t1/t2}$ = .44/.32). Level 3 (*Cardinality and Decomposability*, e.g. 'Lisa has found mushrooms. In which row are there fewer?'; $\alpha_{t1/t2}$ = .20/.11) was assessed using six items, while ten items were used to measure level 4 (*Class inclusion and Embeddedness*, e.g. 'the beaver immediately gives Ben and Lisa the order: 'Bring me 5 flowers, 3 of which should be red'. Can you solve the task with the red and blue tiles? Give me 5 tiles, 3 of which should be red.'; $\alpha_{t1/t2}$ = .76/.80). Level 5 (*Relationality*, e.g. 'Ben and Lisa are collecting stones for another tower. Together they have 6 stones. Lisa has found 4. How many did Ben find?'; $\alpha_{t1/t2}$ = .76/.80) was operationalised using 11 items and level 6 (*Units in Numbers*, e.g. 'Think about how to divide the number 12 into numbers of equal size. Find two ways. Write down your results'; $\alpha_{t1/t2}$ = .71/.78) comprised 13 items.

Material and procedure of the game-playing sessions

The linear board game HoN-20 and the 10-sided dice were used in all of the six game-playing sessions. Two to three children played the HoN-20 game together with a research assistant. As in study 1, the rules of the HoN-20 game were explained to the children in the experimental groups at the beginning, and they received specific or unspecific feedback from the research assistant depending on the group condition. When they landed on fields 9, 12, or 18 on the board, the children were asked to solve special mathematical tasks. As in study 1, the special mathematical tasks were aimed at different levels of the CDM of acquisition of basic arithmetic concepts by Fritz and colleagues (Fritz et al., 2014). As first graders have normally already acquired level 1 and some competencies of level 2, the special mathematical tasks were aimed at the levels 2/3, 4, and 5.

Data analysis

As in experiment 1, descriptive statistics were presented separately for each group. In addition, we conducted a MANOVA and 3×2 mixed-model analyses of variance

Table 4. Descriptive statistics for each condition of experiment 2.

			Specific feedback group		Unspecific feedback group		Control group	
	Min.	*Max.*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre-test								
Total score	14.00	45.00	26.88	7.99	30.56	9.21	30.03	8.83
Level 1/2	4.00	8.00	7.29	0.85	7.11	1.02	7.21	0.98
Level 3	3.00	6.00	5.41	0.87	5.61	0.78	5.34	0.72
Level 4	1.00	10.00	5.59	2.94	6.94	2.39	6.59	2.61
Level 5	0.00	11.00	4.29	2.42	5.44	3.02	5.45	3.02
Level 6	0.00	8.00	2.00	2.00	2.72	2.30	2.59	2.40
Posttest								
Total score	11.00	45.00	34.41	7.90	36.33	9.21	32.62	8.38
Level 1/2	6.00	8.00	7.65	0.70	7.72	0.46	7.55	0.74
Level 3	4.00	6.00	5.71	0.59	5.67	0.49	5.72	0.59
Level 4	0.00	10.00	7.65	2.91	8.28	2.16	7.21	2.48
Level 5	0.00	11.00	6.71	2.66	7.33	3.45	6.07	2.99
Level 6	0.00	11.00	2.35	3.00	4.11	2.85	2.83	2.65

Table 5. Results of repeated measures ANOVA in experiment 2, total scores, levels 1/2 and 3 of mathematical competencies.

	Total scores				Level 1/2				Level 3			
Effect	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2
Time (T)	**61.23**	(1,61)	**.001**	**.50**	**9.93**	**(1,61)**	**.003**	**.14**	**4.09**	**(1,61)**	**.048**	**.06**
Groups (G)	0.58	(2,61)	.565	.02	0.12	(2,61)	.819	.00	0.56	(2,61)	.775	.01
T × G	**71.50**	**(2,61)**	**.009**	**.15**	0.39	(2,61)	.681	.01	0.68	(2,61)	.512	.02
Further results:												
EG1 (T1-T2)	**47.27**	(1,16)	**.001**	**.75**	2.00	(1,16)	.188	.11	1.21	(1,16)	.289	.07
EG2 (T1-T2)	**15.22**	**(2,17)**	**.001**	**.47**	**6.25**	**(2,17)**	**.023**	**.27**	0.06	(2,17)	.816	.00
CG (T1-T2)	**7.84**	(2,28)	**.009**	**.22**	2.79	(2,28)	.106	.09	**6.94**	**(2,28)**	**.014**	**.20**
Performance T1	0.94	(2,61)	.396	.03	0.16	(2,61)	.853	.00	0.66	(2,61)	.519	.02
Performance T2	1.07	(2,61)	.349	.03	0.38	(2,61)	.684	.01	0.06	(2,61)	.944	.00

Note. EG1 = experimental group with specific feedback. EG2 = experimental group with unspecific feedback. CG = control group. T1 = pretest. T2 = posttest. Bold font indicates statistical significance.

Table 6. Results of repeated measures ANOVA in experiment 2 levels 4–6 of mathematical competencies.

	Level 4				Level 5				Level 6			
Effect	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2	*F*	*df*	*p*	η_p^2
Time (T)	**37.54**	(1,61)	**.001**	**.38**	**35.35**	(1,61)	**.001**	**.37**	**4.72**	**(1,61)**	**.034**	**.07**
Groups (G)	0.80	(2,61)	.456	.03	0.49	(2,61)	.616	.05	1.26	(2,61)	.291	.05
T × G	**3.92**	**(2,61)**	**.025**	**.11**	**4.25**	**(2,61)**	**.019**	**.12**	1.43	(2,61)	.248	.05
Further results:												
EG1 (T1-T2)	**15.81**	**(1,16)**	**.001**	**.50**	**28.19**	**(1,16)**	**.001**	**.64**	0.50	(1,16)	.496	.03
EG2 (T1-T2)	**12.95**	**(2,17)**	**.002**	**.43**	**9.95**	**(2,17)**	**.006**	**.37**	3.64	(2,17)	.074	.17
CG (T1-T2)	**5.14**	**(2,28)**	**.031**	**.16**	2.72	(2,28)	.110	.09	0.04	(2,28)	.516	.02
Performance T1	1.25	(2,61)	.293	.04	0.98	(2,61)	.382	.03	0.46	(2,61)	.635	.02
Performance T2	1.00	(2,61)	.373	.03	0.97	(2,61)	.384	.03	1.91	(2,61)	.160	.06

Note. EG1 = experimental group with specific feedback. EG2 = experimental group with unspecific feedback. CG = control group. T1 = pretest. T2 = posttest. Bold font indicates statistical significance.

(ANOVAs) with a between-subject component (specific, unspecific, and control group) and the within-subject factor of change across pre- and posttests (t1 and t2).

Results and discussion

Table 4 depicts the descriptive statistics for each group in experiment 2. Here, the mean of the total mathematical performance of the specific feedback group was somewhat lower than that of the others at t1, but no significant differences were found. Using Pillai's trace, the MANOVA results did not demonstrate any significant differences between institutions in terms of age, gender, or basic arithmetic skills at t1, $V = 0.17$, $F(6,86) = 1.36$, $p = .239$.

A repeated measures ANOVA with the factors time and group showed a significant effect of time and a significant interaction of time and group. Here, the mathematical performance (total score) within each group was significantly higher at posttest compared to the total score at pretest. However, in particular the groups with feedback, and here the group with specific feedback, showed a greater gain in competencies (Tables 5 and 6).

For level 1/2 a significant main effect of time was observed, which was mainly associated with a significant gain of children in the unspecific feedback group. Results for level 3 showed a significant main effect of time which was primarily associated with a significant gain of children in the control group. For level 4, a significant main effect of time and a significant interaction of time and group were shown. Each group increased their mathematical performance on level 4 from pretest to posttest. However, the largest gain was observed for the EGs.

At level 5 a significant main effect of time and a significant interaction of time and group were found. Here, both experimental groups showed a greater competency gain compared to the control group. For level 6, only the main effect of time was significant and no significant differences between the groups were observed.

Taken together, the results of experiment 2 showed that playing the HoN-20 game significantly increased performance in arithmetic tasks compared to children in the control group. Again, the greatest effect size was found in the group with specific feedback, although the gain was significant in all three groups.

General discussion

In contrast to most studies, we analysed not only a global maths score in our two experiments, but also the potential effects on different mathematical competency levels of the CDM. Here, we compared three groups: two groups in which children played the linear board game HoN-20 and received either specific or unspecific feedback and one passive control group. These comparisons were conducted for kindergarten children and for primary school children in first grade.

The findings of both experiments demonstrated that playing the HoN-20 game six times improved children's mathematical performance. These results are in line with previous findings (Elofsson et al., 2016; Laski & Siegler, 2014; Ramani et al., 2012; Skillen et al., 2017), in which children played a linear board game in one-to-one sessions with a research assistant or in groups. It seems that playing in a group and getting feedback immediately from a research assistant fosters mathematical competencies. However, the results of children's mathematical performance in the control group were heterogeneous in the two experiments. In alignment with other studies, preschoolers' maths performance in the control group did not increase significantly. However, first graders who did not play the HoN-20 game and did not receive any feedback, also improved their mathematical performance, although the effect size was somewhat smaller than in the intervention groups. Here it is likely that mathematics instruction during school lessons may have boosted the mathematical skill development of these first graders.

We were specifically interested in establishing whether training effects were evident at different competency levels of the CDM. The results of the first study showed no training effects at levels 1 and 2 of the CDM (Fritz et al., 2013). Possibly, counting (level 1) and the development of the mental number line (level 2) had already been acquired by many of the participating children who played the HoN-20 game and received feedback. In contrast, findings at level 2 were different in the control group, indicating that the mental number line developed between pretest and posttest. The positive training effect at level 3 in both feedback groups indicated that playing the HoN-20 game increased preschoolers' understanding of cardinality and decomposability.

Although the HoN-20 game did not focus on the fourth and fifth levels, some effects were found. Children in the training groups significantly gained level 4 knowledge, whereas no such significant gain was found for the control group for the acquisition of the part-part-whole concept. Playing with dice may support this learning process, for instance, when a preschooler rolled a 3 and another child rolled a 2 and then a 1. However, as no significant interaction effect was found between group and time, this finding has to be interpreted cautiously and more research is needed.

In addition, a positive training effect was found for level 5. Here, preschoolers who received specific feedback had a significantly greater gain. This may be associated with the assumption that specific feedback is very supportive for children's learning (Hattie & Timperley, 2007). According to de Freitas and colleagues (2023) and Johnson and colleagues (2017), it is possible that the processes of extraneous load of these children were reduced by the specific feedback, meaning that the children were more motivated and had more resources available for the intrinsic load of the acquisition of arithmetical concepts. Consequently, the preschoolers in the specific feedback group may have been motivated and used the information provided about the concepts of cardinality and ordinality, which fostered the understanding of each concept and the relationship between both concepts at level 5.

In alignment with the findings of the first experiment, children in experiment 2 in the EGs showed a significantly greater competency gain in levels 4 and 5 compared to children in the control group. As children in the control group also showed a significant gain in level 4 knowledge, it can be assumed that the level 4 concepts seem to be part of regular mathematics instruction in primary school lessons. However, the significantly greater gain for the EGs indicated that playing the HoN-20 game and getting feedback seemed to support the acquisition of class inclusion, embeddedness, and relationality.

No training effects were found at levels 1/2 and 3. First graders who played the HoN-20 game and received feedback, may have already acquired a mental number line and the concepts of cardinality and decomposability. However, children in the control group showed significant learning gains at level 3 which did not differ significantly from the learning gains of the EGs. These findings indicated that children in the control group developed a better understanding of cardinality and decomposability between pretest and posttest, possibly supported by the teaching in maths classes. No training effects were observed for level 6. This was not surprising as the competence of bundling a number into partial segments (Fritz et al., 2013) occurs later in the developmental process.

Altogether, children in the control group primarily showed significant achievement gains at lower levels, which indicated the development of basic arithmetic skills. In comparison, children in the EGs showed greater gains at levels 3 to 5 and thus in more advanced arithmetic skills. Here, the effects in the specific feedback group were larger and it can be assumed that these children were able to use the information from the specific feedback effectively for the acquisition of basic and more advanced arithmetic skills.

Limitations

As with the majority of studies, our two experiments were subject to several limitations. First of all, we were not able to do a follow-up assessment in both studies. Consequently, we could not test whether the training effects were stable over time. Second, in both experiments, the participating children played the HoN-20 game in a rather controlled laboratory-like setting. Consequently, the results cannot be directly generalised to educational settings. Third, the children played in groups with a trained research assistant. In a next step, these studies should be repeated in a group setting with (pre)school teachers or with peers only.

Fourth, neither the version of the linear board game, which was used in the experiments, nor the feedback were adaptive. This means that in the game-playing sessions, we did not consider a child's individual development of mathematical skills. Nor did we provide individualised feedback adapted to children's characteristics. Consequently, for some children the content of the board game may have been too advanced, whereas other children may have already mastered most mathematical concepts before the first play session. Further research should take this into account and use adaptive special tasks of the HoN-20, tailored to the individual mathematical needs of children playing this game. It should also give adaptive feedback in line with the children's individual characteristics.

Finally, we did not measure and control for children's characteristics such as socio-economic status, migration background, or intelligence, teachers' activities in (pre)school and parents' activities at home. Research indicates that both – the characteristics of the home learning environment and of formal education and care – have an impact on child development (e.g. Niklas & Tayler, 2018). However, these differences should already be evident in children's competencies at t1 in our studies and the intervention phase of a couple of weeks is probably too short for these environmental factors to have a major impact on competencies' development in this period. Future research should control teachers' instruction in (pre)school as well as the parental home numeracy environment of participating children.

Conclusion

To summarise, the results of our two experiments demonstrated that playing the linear board game HoN-20 boosted children's development of basic mathematical skills in both preschool and primary school. Moreover, the type of feedback provided to children whilst playing this game also made a difference. Whereas children in both feedback groups showed a significantly greater competency development compared to the control group, the greater gains were observed for the group who received specific feedback. Finally, playing the HoN-20 game and receiving feedback seemed to impart more advanced arithmetic basic knowledge concerning cardinality, ordinality, and part-part-whole understanding.

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

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