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Developing arithmetic skills in kindergarten through a game-based approach: a major issue for learners and a challenge for teachers

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ABSTRACT
Early arithmetic skills, and in particular the understanding of the part-whole relationship, are currently considered crucial for future arithmetic achievement. They are complex skills extending far beyond the mastery of counting procedures. In order to develop these arithmetic skills in kindergarten children, we developed a game-based approach using conventional card and board games adapted to the targeted mathematical objectives. The present study examines the effects on the arithmetic skills of this game-based approach. Individual pre-and post-tests were administered to 194 children (5–6 years old) from four countries (play-based group $n = 104$ and control group $n = 90$). Our findings show that the learning outcomes of the game-based group were significantly higher than those of the control group after the intervention. The game-based group showed improvements in arithmetic skills, and in particular those relating to the part-part-whole relation. The intervention also resulted in all pupils, regardless of their initial proficiency level and including those regarded as 'at risk', making more progress than those in the control group. These results demonstrate the possibility of developing complex mathematical learning effectively in preschool in a manner consistent with the needs and interests of young children.

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early childhood education; arithmetic skills; part-part-whole; game-based approach; quasi-experimental design

Introduction

In recent years, a large body of research has highlighted the importance for later achievement of the development of early number skills in preschool children[1] (Aunio and Niemivirta 2010; Dyson, Jordan, and Glutting 2013; Nguyen et al. 2016; Purpura and

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Lonigan 2013). These early number skills can be categorised into three distinct but closely related factors: numbering, relations and arithmetic operations (Dierendonck et al. 2021; Purpura and Lonigan 2013). Skills in arithmetic operations in particular have been the subject of growing interest in recent years (Cheng 2012; Kullberg et al. 2020; Laski, Ermakova, and Vasilyeva 2014; Tsamir et al. 2015). Researchers argue that these arithmetic skills, comprising addition/subtraction strategies and (de)composition of numbers, make it possible for children to start acquiring at preschool level a conceptual understanding of mathematical operations that is essential in primary education (Cheng 2012).

Operations sense and computational fluency are a key issue in primary education (Carpenter et al. 1997; Guerrero and Palomaa 2012). However, some studies have highlighted the difficulties experienced by students in the field of addition and subtraction operations, in particular because of their exclusive reliance on the procedural and symbolic aspects and on methods which have been learned by heart (e.g. Guerrero and Palomaa 2012). One way of lessening these difficulties is for pupils to gain a deeper understanding of the meaning and the conceptual aspect of these operations. In this context, working on part-part-whole relations at preschool, thus smoothing the transition to grade 1 arithmetic learning, could be a promising approach (Baroody 2016; Cheng 2012; Kullberg et al. 2020). These skills refer to the ability to perceive the relation between the whole and its parts and thus to understand that a number may be composed of other numbers (Cheng 2012; Resnick 1983). Developing arithmetic skills in preschool does not mean teaching formal arithmetic operations ahead of time, but using meaningful activities to develop specific mathematical concepts that will enable them to approach arithmetic learning more effectively later on (Gasteiger, Obersteiner, and Reiss 2015).

Playing games, such as conventional board and card games which are adapted to specific mathematical objectives have the potential to perform this function, in a manner that is consistent with the children's interests and well-being (Gasteiger, Obersteiner, and Reiss 2015; Hassinger-Das et al. 2017; Vogt et al. 2018). To date, however, few studies have examined the learning of arithmetic skills in preschool, and none to our knowledge, has specifically developed these skills using conventional card and board games.

The main purpose of this paper is to investigate the impact of a game-based approach using card and board games that is designed to develop the arithmetic skills of kindergarten children (grade K) (5–6 years old).[2] The skills involved in these games are the addition of two quantities and the decomposition of numbers in relation to a part-part-whole understanding of operations.

Theoretical background

Arithmetic skills

While the importance of counting has been widely demonstrated, it is equally widely accepted that children need to gradually move beyond counting procedures if they are to perform addition and subtraction effectively in primary school (Cheng 2012; Kullberg et al. 2020). However, Kullberg et al. (2020) have noted that for a long time, the focus has been on the development of counting and counting-on skills, from which children learn to add and subtract numbers. Following the work of Carpenter and Moser (1984) in particular, it was long thought that children's strategies spontaneously evolved from essentially material strategies (e.g. counting everything) to essentially verbal strategies (e.g. counting-on) and then mental strategies (decomposition or fact retrieval). This evolution of strategies is necessary to develop an understanding of number and arithmetic relations. However, some researchers now believe not only that the transition from verbal strategies to decomposition strategies does not necessarily happen spontaneously in all children, but also that counting and counting-on strategies could hamper the development of more advanced strategies in tasks such as finding the missing addend in 3 + _ = 8 (Cheng 2012; Kullberg et al. 2020): simply counting on from 3 will not necessarily allow the child to find the answer if he/she does not know that 8 refers to a whole made up of 3 and another unknown part. The challenge is that counting and counting-on do not emphasise the relations between numbers, such as the number triad 3-5-8 in the example above. For many authors, such as Kullberg et al. (2020), Laski, Ermakova, and Vasilyeva (2014), and Tsamir et al. (2015), part-part-whole relations are at the heart of arithmetic skills. How, then, can this understanding be developed in young children? Some authors (Cheng 2012; Kullberg et al. 2020) believe that this involves enabling children to immediately recognise the different (de)compositions of numbers without going through the stage of counting one by one. To this end, they have shown the effectiveness of activities based on the use of fingers to represent different number patterns.

Developing a grasp of part-part-whole relations thus seems to foster a rich understanding of numbers and operations. In grade 1, pupils who use mental decomposition strategies seem to demonstrate a deeper conceptual understanding of addition and subtraction than those who continue to use counting-on (Fennema et al. 1996). This is because when children understand the relation between the parts and the whole simultaneously, the tasks of addition and subtraction are made easier (Cheng 2012; Mulligan and Mitchelmore 2009). Furthermore, Tsamir et al. (2015) have shown that the ability to compose and decompose numbers flexibly allows children to apply varying strategies to solve problems in different contexts. In addition, according to Laski, Ermakova, and Vasilyeva (2014), these (de)composition skills play a vital role at primary level in the understanding and use of the going-through-ten strategy (e.g. 7 + 5 = 7 + 3 + 2 = 12).

It, therefore, seems essential for future learning and the development of more advanced skills to start attaching great importance in preschool to these part-part-whole relations. Various interventions have recently been carried out to promote the learning of these relations in kindergarten children. They have shown that pupils at this level are perfectly capable of developing these skills and that this has a very positive impact on their understanding of the relations between numbers (Björklund, Kullberg, and Kempe 2019; Cheng 2012; Tsamir et al. 2015). But until now, it seems that no intervention has developed an approach specifically for this learning, which takes into account the child's development and interests. With this goal in mind, we have developed a game-based approach.

A game-based approach

Play is recognised as highly suitable for young children (Gasteiger, Obersteiner, and Reiss 2015; Magnusson and Pramling 2018), and its effectiveness in developing mathematical skills in preschool pupils has been demonstrated many times (Edo, Planas, and Badillo

2009; Gasteiger, Obersteiner, and Reiss 2015; Vogt et al. 2018). For El'konin (as quoted in van Oers and Duijkers 2013), from a developmental point of view, play is the main and most productive context for learning in children aged 4–7 years. Vogt et al. (2018) further point out that direct and intentional instruction is not appropriate for young children; it can even create anxiety and lower self-esteem (Gasteiger, Obersteiner, and Reiss 2015).

Play is often defined as activities that are fun, voluntary, challenging, intrinsically motivated, without extrinsic goals, and involving active engagement (Hassinger-Das et al. 2017; Vogt et al. 2018; Weisberg, Hirsh-Pasek, and Golinkoff 2013).

As a form of play, games may constitute an efficient pedagogical tool for the pursuit of both developmental and cognitive objectives. Games can be seen as enjoyable and challenging play activities that follow specific rules (Gasteiger, Obersteiner, and Reiss 2015), but they can also be used to target the desired mathematical skills more effectively than free play, during which it is not always certain that these skills will be encountered (Hassinger-Das et al. 2017).

Few studies have taken an interest in the characteristics of the games themselves. Yet, according to Gasteiger, Obersteiner, and Reiss (2015), not all activities that are labelled as games are actually enjoyable and challenging activities. In the scientific literature, the term 'game' is used equally to denote adult-directed mathematical activities (Kullberg et al. 2020; Ollivier et al. 2020), adult-directed board games (Ramani and Siegler 2008) or child-directed card and board games (Gasteiger, Obersteiner, and Reiss 2015; Vogt et al. 2018). The adult-directed 'games' tend often to be school tasks disguised as a game, a bit like 'chocolate-covered broccolis' (Vogt et al. 2018).

In our study, like Gasteiger, Obersteiner, and Reiss (2015), we chose games originally designed for the purpose of entertainment, namely conventional card and board games, which therefore corresponded to the definition of 'play' set out above. In this sense, we regard these games as 'genuine' games. In addition, these games feature additional motivation factors, as they involve competition between players or collaboration between players contending against a common opponent (Gasteiger, Obersteiner, and Reiss 2015; Hassinger-Das et al. 2017).

As the games involved in our study were also intended to support the learning of specific mathematical content, that content had to be included. However, in order for the game to retain an entertainment purpose, the mathematical content needed to be part of the mechanics of the game (Gasteiger, Obersteiner, and Reiss 2015; Vogt et al. 2018) so as to develop intrinsic motivation. In other words, mathematical knowledge is used during these games in order to play and win, without any extrinsic goals.

However, playing this kind of game is often not enough to achieve learning objectives (Broström 2017); nor is it enough for mathematical concepts to be present in the game (Björklund, Magnusson, and Palmér 2018). According to Weisberg, Hirsh-Pasek, and Golinkoff (2013), the adult must play an active role for the children to be able to achieve the learning goals. With this in mind, these authors have defined the concept of 'guided play'. For them, this approach stands between free play and direct instruction; the adult's role consists of structuring the play environment and scaffolding children's exploration while leaving control of it to them.

However, like Hassinger-Das et al. (2017) or Broström (2017), we maintain that during play, adults should not intervene or direct the play activity too much. If the adult takes too much control, the play activity is likely to hamper the child's initiative, motivation and interest (Broström 2017). With such an approach, however, is there not a risk that mathematical learning will be sidelined? To avoid this pitfall, we believe it is more appropriate for the teacher's interventions to take place mainly before and after the game, so as to leave its actual progress under the control of the children. Before the game, the adult designs and provides appropriate materials, in this case, card and board games adapted to the learning objectives. During the game, the teacher should preferably remain in the background, observing what the children are doing and saying. After the game, it is important for teachers to organise short discussions about the strategies used by the children during the game or to talk them through some fictitious games in order to take things further. These discussions will be all the more effective if the teachers are able to see the 'children's perspectives', i.e. to be aware of the different ways in which children have understood the content involved in the games (Pramling Samuelsson and Björklund 2022). The objective is what van Oers and Duijkers (2013) call 'mathematizing elements of play' which implies that mathematical concepts or operations involved in the game are explored further on the basis of children's own contributions. Thus our game-based approach is fully in line with the 'developmental pedagogy' recently defined by Pramling Samuelsson and Björklund (2022), where play and learning are integrated in preschool education and where the 'children's perspective' is a key feature.

We contend that children are more likely to experience the activity in this kind of game-based approach as meaningful, in the sense of the term used by Broström (2017), in that they have control of the activity and are conscious of what they are doing, how they are doing it and for what reason(s) they are doing it. This will lead to more active and voluntary engagement.

The present study

The data used in the present study come from a larger study that aims to evaluate a game-based intervention for enhancing children's numerical skills at school and at home for children aged four to six years (de Chambrier et al. 2021). This research was carried out jointly in four countries (Belgium, France, Luxembourg and Switzerland) and involved a total of eight games, which were implemented by trained teachers in whole-class groups during eight weeks (one game per week). These consisted of conventional card and board games which had been adapted to mathematical objectives relating to the numbering, relations and arithmetic operations skills mentioned at the beginning of this article.

Kindergartens with mixed socioeconomic backgrounds were contacted in the local areas of the four participating universities. Teachers interested in the study were asked to participate to experimental or control condition on a voluntary basis. The comparability of experimental and control group were controlled before and after quasi-experimental study (see de Chambrier et al. 2021 for more information). The study was approved by the Ethics Review Panel of the University that coordinated the project (University of Luxembourg). In every country, consent forms were requested and received from the school authorities and from the children's parents.

Each teacher in the experimental groups attended a professional development programme consisting of three or four half-day workshops (depending on the country).

These workshops focused on early number skills acquisition, exploration of the games, school–family relationships, the difficulties the children might encounter, and the help that could be provided. The arithmetic skills targeted by each game were presented and discussed in order to provide the teachers with some guidelines for 'mathematizing elements of play' (van Oers and Duijkers 2013) in the discussions after the game.

The present study focuses on the arithmetic skills that were developed during the last four weeks of the intervention through four games, three of which targeted number composition and decomposition, while the fourth focused on addition. As these skills are crucial for the transition to grade 1, only grade K children were taken into consideration.[3]

More specifically, this paper aims to answer the following general research question: What are the effects of a game-based approach characterised by 'genuine' card and board games, on the arithmetic skills of grade K children?

We also defined two sub-questions: Were the effects of the approach the same for each kind of arithmetic skills activity (addition operations, problem solving or decomposition activities), and did they differ according to children's initial proficiency level?

Method

Participants

This article relates to 194 children attending the grade K (101 girls and 93 boys ; mean age 5 years, 6 months). The experimental group consisted of 104 children, who played four games in class that had been designed by the research team (Game-based group – GbG), while the control group consisted of 90 children who followed the everyday classroom routine (Control group – CG).[4]

Intervention games

The card and board games were offered to the children by the teachers themselves in the usual class context. Each of the four games was played during one week in four separate 20-minute play sessions. After being introduced to the rules, the children played in small groups relatively independently, and after the game brief discussions took place between the teacher and the children as described above.

The four games designed to develop arithmetic skills are briefly summarised below (for more details, see de Chambrier et al. 2021) Table 1.

These games can be considered 'genuine' games in that they are designed to satisfy the definition of 'play'. Arithmetic skills are integral to the dynamics of each game. For example, children need to decompose the number on the dice in order to advance two pieces on the board strategically (Rabbits and Carrots), or even add the values of two cards to find out who has the higher total (Addition Battle). Children act mathematically, not for a purpose extrinsic to the mathematical activity, for example in response to an instruction from the teacher, but in order to engage in the competition and win. As conventional card and board games, these games are designed to be played under the children's control.

Table 1. Description of the four maths games and the targeted skills.

Games	Description	Arithmetic skill	Number size usually involved in the game
The Dragon's jail	The objective of this cooperative game is to shut the dragon up in a prison with the bricks using a dice. The game is designed to make it strategically useful to decompose the number of each dice roll.	Number composition & decomposition	Maximum 5
Rabbits and carrots	This is a linear board game in which each player has two pieces. Each player rolls a dice and can decompose the number rolled to move his or her two pieces separately. The winner is the first player to get both pieces on the last square.	Number composition & decompositon	Maximum 6
The Extra card	This game is based on the rules of the game 'Black Jack'. The children must form pairs of cards that correspond to a given number. The winner is the first player to get rid of his/her cards, while the player ending with the 'extra card' (the 'Balck Jack') loses.	Number composition & decomposition	Maximum 6 (occasionally more, depending on the level of the children)
Addition battle	This game resembles the traditional card game 'Battle', but instead of playing one card at a time, each player turns over two cards and adds them up. The player has the higher total can take all the other cards.The winner is the player who wins all the cards.	Addition	Maximum 6 (occasionally more, depending on the level of the children

Pre- and post-test

All the children were tested individually before and after the intervention. Their early numerical skills were assessed using a test largely inspired by the TEDI-MATH (Van Nieuwenhoven, Grégoire, and Noël 2001) and TEMA-3 (Ginsburg and Baroody 2003) test sets. The final version of the tool used in this study consisted of 34 items. The same tool was used for pre-test and post-test (de Chambrier et al. 2021). In this test, ten items specifically assessed arithmetic skills (Cronbach's alpha: 0.72). These items are presented in Table 2 below.

Table 2. Presentation of the 10 items composing the arithmetic score.

Item type	Number of items	Description	Abbreviation	Operation
Arithmetic operations	3	The children were asked to say how many counters there were in two sets.	AO1	2 + 1 = ?
			AO2	3 + 2 = ?
			AO3	5 + 3 = ?
Problem-solving	3	The children were asked to solve three problems out loud:		
		1 direct addition problem	PS1	4 + 3 = ?
		1 direct subtraction problem	PS2	6-2 = ?
		1 addition problem with a missing addend	PS3	8 = 5+ ?
Additive decompositions	4	The children were asked to count a collection of rabbits and then, after the experimenter had hidden a number of rabbits in a 'burrow' (cup), to work out how many rabbits from the collection had been hidden in the 'burrow'.	AD1	5 = 2+ ?
			AD2	5 = 4+ ?
			AD3	9 = 5+ ?
			AD4	9 = 3+ ?

Results

General results

Table 3 shows the progress of the experimental and control groups between pre-test and post-test. The results show that both groups progress between pre- and post-test, but that the gain is higher for GbG compared to that of CG.

The repeated-measures ANOVA[5] revealed a significant effect related to time (F[1,192] = 44,117; $p = .000$]) as well as to the intervention, with a significant difference in favour of GbG compared to CG (F[1,192] = 12,162; $p = .001$]). In other words, the intervention had a significant effect on this arithmetic proficiency. The calculation of the effect size in accordance with the method described by Morris (2008) results in $d = .40$.

Beyond this first general finding in favour of the GbG pupils, it would be interesting to know whether the progress of these children related more to some items than to others, or whether certain pupils (the weak, average or strong pupils) made more progress than others. These questions are analysed in the following sections.

Analyses by item

Table 4 shows the correct answers in percent on the 10 items constituting the arithmetic score and Figure 1 shows the relative gains between pre- and post-test.

The results in Table 4 show that at pre-test, both groups did best at the items involving adding numbers up to 7 – whether in arithmetic operations or in problem-solving – with correct answer rates close to or greater than 50% (AO1, AO2 PS1 and AD2).

Table 4 and Figure 1 clearly show that at post-test, the learning outcomes for GbG pupils had increased higher than for CG on all items (with the exception of AO1, for which there was a ceiling effect with a correct answer rate of around 90% at pre-test).

This difference was mainly apparent in four items from the three categories: arithmetic operations (AO2, with a 13% difference in relative gain), problem-solving involving addition (PS1, with 14%) and subtraction (PS2, with 14%), and above all, additive decomposition AD2 (23%). The largest number to be decomposed in these items was 7, which appears to have played a role in the children's progress. This may be related to the numbers involved in the games which, for the most part, did not exceed 6. When the numbers were larger (8 or 9), the difference in relative gains was less marked, although still in favour of GbG.

The greatest improvement was on item AD2, which involved the decomposition of 5 into 4 + ?. While the numbers did not exceed 5 and the missing term was only 1, the results obtained for this item by the two groups at pre-test were strikingly weak. This suggests that the quantities to be enumerated are not the only obstacle, and that the difficulty also lies in the actual task of decomposition. At post-test, CG, which had had

Table 3. Scores (means and standard deviations) in pre- and post-tests, learning gains and effect size.

	M (SD) Pre-test	M (SD) Post-test	M Learning gains	Effect size D_{ppc2}
Game-based group (GbG) (N = 104)	**39.90 (24.63)**	**53.46 (26.32)**	**+13.56**	**0.40**
Control group (CG) (N = 90)	39.44 (21.90)	43.67 (25.06)	+4.23	

Note: No differences between the groups at pre-test (ANOVA: F[1,192] 0.019; $p = .892$ *n.s.*).

Table 4. Comparison of correct answers in percent on the 10 items relating to arithmetic skills at pre- and post-test.

Pre-test										
	AO1 2 + 1 = ?	AO2 3 + 2 = ?	AO3 5 + 3 = ?	PS1 4 + 3 = ?	PS2 6-2 = ?	PS3 8 = 5+ ?	AD1 5 = 2+ ?	AD2 5 = 4+ ?	AD3 9 = 5+ ?	AD4 9 = 3+ ?
GbG (*N* = 104)	87.5%	57.7%	43.3%	52.9%	27.9%	11.5%	37.5%	46.2%	19.2%	15.4%
CG (*N* = 90)	81.1%	62.2%	37.8%	48.9%	31.1%	14.4%	33.3%	56.7%	18.9%	10.0%
Post-test										
	AO1 2 + 1 = ?	AO2 3 + 2 = ?	AO3 5 + 3 = ?	PS1 4 + 3 = ?	PS2 6-2 = ?	PS3 8 = 5+ ?	AD1 5 = 2+ ?	AD2 5 = 4+ ?	AD3 9 = 5+ ?	AD4 9 = 3+ ?
GbG (*N* = 104)	91.3%	69.2%	58.7%	63.5%	47.1%	19.2%	53.8%	71.2%	37.5%	23.1%
CG (*N* = 90)	86.7%	61.1%	51.1%	45.6%	35.6%	12.2%	43.3%	58.9%	27.8%	14.4%

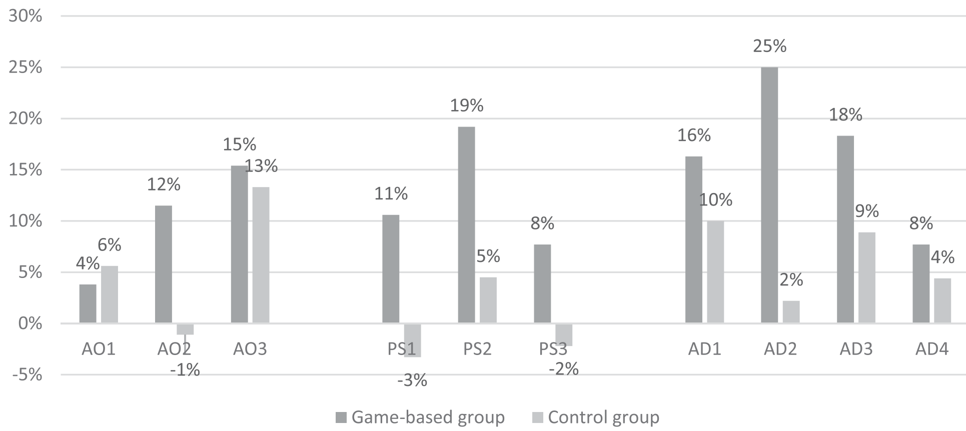

Figure 1. Relative gains between pre- and post-test for the 10 arithmetic items.

a slightly higher correct answer rate than GbG at pre-test, showed hardly any improvement (+ 2%). By contrast, GbG score had increased of 25%. This item also showed the greatest difference in relative gain. This may point to the effect of the games on the part-part-whole understanding, in particular for the triad 4-1-5, which was probably situated more in the children's zone of proximal development than the other decomposition items – this was already the decomposition item with the highest correct answer rate at pre-test for pupils in both groups.

Analyses according to initial proficiency level

Figure 2 illustrates the progress made by pupils based on their initial proficiency level. The 194 pupils were divided into quartiles on the basis of their proficiency across the entire pre-test, which, it will be recalled, consisted of 34 items (including the 10 items making up the arithmetic score). For each quartile formed in this way, the arithmetic proficiency scores were then calculated at pre- and post-test.

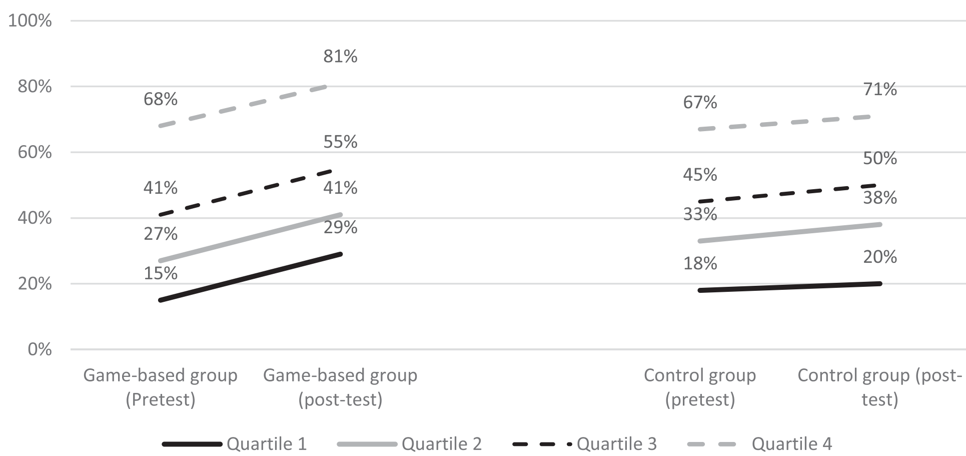

Figure 2. Improvement between pre- and post-test according to initial proficiency level.

The results show greater progress for all quartiles in the GbG. The improvement there was around 13 to 14% for the four quartiles, whereas in the CG it was no more than 4 to 5% for the top three quartiles and was negligible (2%) for the bottom quartile.

The games therefore had a positive effect for all GbG pupils, regardless of their initial level. In other words, 'weak' pupils (quartile 1) benefited as much from the intervention as 'strong' pupils (quartile 4). However, the intervention did not reduce the performance gaps between these two extremes. In the CG, the performance gaps between the subgroups of pupils were just as large, but the gap tended to increase slightly to the detriment of 'weak' pupils (quartile 1).

Discussion

The challenge of our study was to develop complex mathematical skills such as arithmetic skills at preschool, while supporting children's development and satisfying their need to play. To this end, we developed a game-based approach based on conventional card and board games adapted to the targeted arithmetic objectives. This is consistent with the 'developmental pedagogy' defined very recently by Pramling Samuelsson and Björklund (2022).

Our results confirmed that arithmetic skills are difficult for children aged 5–6 years. The poor pre-test results bore witness to these difficulties, which have been pointed out in the research literature. Decomposition skills are often regarded as particularly difficult (Cheng 2012), but even the 'simple' skill of adding two numbers can be an obstacle for young children (Bjorklund and Rosenblum 2001; Moomaw and Dorsey 2013).

Our intervention proved to be effective, enabling the children in GbG to progress significantly more than those in CG. The intervention had an effect size of 0.40, which can be regarded as considerable compared with other studies involving similar characteristics (Mononen et al. 2014).[6]

More specifically, the item-by-item analysis showed that the improvements in GbG relative to CG concerned all category of arithmetic skills activities, and in particular those where the numbers did not exceed 7. However, this criterion is insufficient to explain these results. From pre-test, almost all pupils in this group (93%) could easily count random collections of up to 8 rabbits (de Chambrier et al. 2021). If the correct answer rate for the items making up the arithmetic score was merely a matter of number size, all items involving numbers up to 8 should have been completed by about 90% of the pupils; however, this was far from the case.

Moreover, the significant improvement observed in the additive decomposition item '5 = 4 + ?' in particular is striking. It is likely that the improvement of the GbG pupils does not point to a procedural strategy involving counting or counting-on of 5 objects, but rather reflects a conceptual understanding of the part-part-whole relationship. The difficulties observed at pre-test and those that remained at post-test (especially for CG) show that, even with these small numbers, this relation is not self-evident and that simply counting on 1 after 4 is not enough to allow children to understand the relations between these three numbers. The improvements in the other additive decompositions were slighter, even when the items still involved decomposing 5. Our intervention was probably too short to allow all the children to consolidate and automate their learning of number decomposition up to 5.

Regarding the children's initial proficiency level, the results showed that the games allowed all GbG pupils to progress more than those in CG and in particular those in quartile 1, even though their post-test scores remained low. These children can be considered as at risk as regards future arithmetic learning. The poor results obtained by them are consistent with the findings from several early numeracy interventions for children at risk examined in the meta-analysis by Mononen et al. (2014). These authors also found that although at-risk children made significant progress, their performance still lagged well behind that of their peers. They also drew attention to the fact that these pupils' progress was most marked when the interventions included pedagogical features such as the introduction of games and working in small groups. Our intervention, which included these characteristics, proved effective for at-risk children. However, why did it not lead to better results and reduce the gaps between at-risk children and their peers? The reason may lie in the exchanges between the teacher and the children, which may not have been effective enough. It is up to the teacher to mathematize the elements of the game (van Oers and Duijkers 2013), in other words to make them explicit through brief discussions involving all pupils, including the weakest. According to Björklund, Magnusson, and Palmér (2018), the key here is being 'responsive' to the children's ideas. However, such a role is challenging for many teachers. Wickstrom, Pyle, and DeLuca (2019) showed that in guided play, teachers found it hard not only to strike the right balance between free play and direct instruction, but to provide optimal teacher involvement to support academic learning. The effectiveness of the game-based approach will therefore also depend on the quality of interventions on the part of the teacher. Weisberg et al. (2016) point out that one of the challenges for future research will be determining exactly which aspects of adult-provided guidance are most effective.

Conclusion

The results of our study demonstrated the effectiveness of having children play 'genuine' card and board games in order to develop arithmetic skills. It could be objected that other types of activity of a more teacher-directed nature have also proved effective for children learning (e.g. Ollivier et al. 2020; Ramani and Siegler 2008), but with the difference that the former meets the needs of young children whereas the second is much less suitable (Vogt et al. 2018).

Our study took place in the context of a larger quantitative study measuring a set of numerical skills in pupils aged 4–6 (de Chambrier et al. 2021). In addition to the limitations already mentioned for this larger study, the main limitation of our study concerns the lack of data relating to the strategies developed by kindergarten children to perform tasks relating to arithmetic skills. Such data would have given us a better understanding of the effect of our intervention.

Finally, it is surprising that until now, no study has used a child-directed game-based approach for specifically developing the arithmetic skills, compared with the many studies focusing on adult-led activities. Here, a recent and unfortunate trend should be noted: the increasing prevalence of preschool curricula and assessment materials that focus solely on teaching content (Weisberg, Hirsh-Pasek, and Golinkoff 2013). In terms of teaching practices, this has led some scholars (Doabler and Fien 2013) to claim that formal direct instruction is the most effective approach to promote early mathematical skills, especially for at-risk children. As Pramling Samuelsson and Björklund (2022) emphasise, these exclusive expectations of academic outcomes in preschool are alarming, and may contribute to the risk of 'hijacking' play/games to justify learning, and of turning them into 'chocolate-covered broccolis' (Vogt et al. 2018).

Our study showed that, in fact, an intervention that is sensitive to children's development is beneficial even for children at risk. This type of game-based approach allows pupils to experience the activity as 'meaningful' (Broström 2017), and seems to be a promising way to develop mathematical learning in preschool.

Notes

1. By preschool, we mean all schooling before entry into primary school (grade 1); depending on the country, it may concern children from 3 or 4–6 years old.
2. By kindergarten (or grade K), we mean the last year of preschool before grade 1, for children from 5 to 6 years old.
3. As noted above, the larger study compared classroom and family interventions. This study focuses exclusively on classroom interventions.
4. The two groups were equivalent in terms of average child age (5 years 6 months), but differed slightly in terms of the representation of the two sexes (53% girls in the GbG, but 51% in the CG). Moreover, as we will explain later, the two groups' scores were completely comparable at pre-test (the difference was non-significant: see the 'General results' section).
5. Levene's tests revealed no violation of the assumption of homogeneity of variance between groups on the two test occasions (FPre (1,192) = . = 3.055, p = .082 *n.s.*).
6. From the interventions covered by the meta-analysis of Mononen et al. (2014) relating to at-risk children, only two core instruction interventions share some features with our intervention: Chard et al.'s study with an effect of 0.33 for a 25-week intervention and Clarke et al.'s study with effects from 0.03 to 0.36 for a year-long intervention, both with 5-year-old children. Although it did not relate exclusively to an at-risk group, the effect of our intervention was slightly greater despite being significantly shorter than these two studies (8 weeks in total, including 4 devoted to arithmetic games).

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