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How Informal Learning Activities Can Promote Children's Numerical Knowledge

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Abstract and Keywords

Before children begin school, there is a wide range of individual differences in children's early numerical knowledge. Theoretical and empirical work from the sociocultural perspective suggests that children's experiences in the early home environment and with informal number activities can contribute to these differences. This article draws from this work to hypothesize that differences in the home explain, in part, why the numerical knowledge of children from low-income backgrounds trails behind that of peers from middle-class backgrounds. By integrating sociocultural perspectives with a theoretical analysis of children's mental number line, the authors created an informal learning activity to serve as an intervention to promote young children's numerical knowledge. Our studies have shown that playing a simple number board game can promote the numerical knowledge of young children from low-income backgrounds. The authors discuss how informal learning activities can play a critical role in the development of children's early maths skills.

Keywords: maths, preschoolers, informal learning activities, interventions, board games

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Providing children with a strong foundation of mathematical knowledge is critical for success in school and beyond. Children's early mathematical knowledge predicts their rate of growth in mathematics (Aunola, Leskinen, Lerkkanen, & Nurmi, 2007; Jordan, Kaplan, Locuniak, & Ramineni, 2007), as well as mathematics achievement test scores in later elementary school and even into the high school years (Duncan et al., 2007; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Locuniak & Jordan, 2008; Mazzocco & Thompson, 2005). Furthermore, mathematical achievement can impact children's performance in college and choice of careers (National Mathematics Advisory Panel, 2008).

Given the importance of maths education, the development of maths skills has been extensively researched over the past 20 years (Dehaene & Brannon, 2011; Geary, 2006). One specific area of interest is the wide range of individual variations in children's mathematical knowledge. Of particular concern to educators, policymakers, and parents is that many of these differences are evident prior to children beginning school. Individual differences in the numerical knowledge of preschool and kindergarten children have been demonstrated on a variety of foundational maths skills, such as counting, identifying written numerals, and simple arithmetic (see National Research Council of the National Academies, 2009, for a review). These early differences tend to increase the further children move through school (Alexander & Entwisle, 1988; Geary, 1994, 2006). Therefore, understanding the kinds of experiences that promote early numerical knowledge is of critical importance because it can impact children's long-term maths achievement in school and possibly their long-term career opportunities.

In this article, we review recent research on how children's early experiences in the home and, with informal learning activities, can influence their mathematical understanding and performance. First, we present a growing body of literature that demonstrates from a sociocultural perspective how contextual factors and early experiences, mainly with parents in the early home environment, can shape children's numerical development and can explain individual differences in numerical knowledge. Second, we review theories and empirical work regarding a specific aspect of numerical knowledge, the mental number line, which likely underlies children's number sense. Finally, we argue that by integrating this theoretical analysis of the mental number line with a sociocultural perspective can help inform the design of activities to promote children's numerical knowledge. To support our argument, we review research that we have conducted that shows that playing a linear number board game can promote the numerical

knowledge of preschool-age children from low-income backgrounds.

Sociocultural Perspectives on the Development of Numerical Knowledge

The sociocultural perspective provides an impetus for examining how children's early home environment and interactions with adults can influence children's mathematical development. A central tenet of sociocultural theory is that social interactions with adults play a critical role in children's cognitive development (Gauvain, 2001; Rogoff, 1990; Vygotsky, 1976, 1978). Play and other informal activities are considered particularly important contexts in which adults provide children with new information, support their skill development, and extend their conceptual understanding. Every-day, informal activities can provide children with extensive numerical information in the home environment (Saxe, 2004). Furthermore, much of the development of mathematical understanding in early childhood is social in nature, occurring during activities with parents, such as meals, chores, and shopping. For example, a young child could learn about one-to-one correspondence, while setting the table, fractions while cooking, and arithmetic while at the grocery store.

The sociocultural perspective has also motivated research on how children from different cultural and socioeconomic status SES backgrounds can vary in numerical knowledge and how these differences are influenced by their early home experiences. Differences in mathematical knowledge between children from China and the United States have been found in preschoolers as young as age 3 years (Miller, Kelly, & Zhou, 2005). The advanced number skills of young Chinese children have been shown on familiar tasks, such as arithmetic problems, and also on novel tasks, such as a number line estimation task (Siegler & Mu, 2008). These differences are related to early home experiences – Chinese parents practice skills such as arithmetic at home much more than US parents do (Zhou, Huang, Wang, Wang, Zhao, Yang, L., et al., 2006) – and also to general societal differences, such as variations in number names (Miller et al., 2005).

Even within the United States, young children's maths achievement and their mathematical experience vary widely. Specifically, the numerical knowledge of young children from low-income backgrounds trails far behind that of their peers from middle-income backgrounds. These differences do not extend to all numerical tasks. On non-verbal numerical tasks, the performance of young children from low-income backgrounds is equivalent to that of age peers from wealthier backgrounds (Jordan, Huttenlocher, & Levine, 1992; Jordan, Levine, & Huttenlocher, 1994). However, the same studies find large differences on tasks with verbally stated numbers, story problems, written numerals, and higher-level maths problems. Specifically, differences have been found in areas such as knowing the cardinality principle when counting, identifying written numbers, and solving arithmetic problems (Lee & Burkam, 2002; Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006; Saxe, Guberman, & Gearhart, 1987; Starkey, Klein, & Wakeley, 2004). These symbolic tasks are foundational for later mathematical concepts and, therefore, are the focus of the research presented in this article.

Numerical Activities in the Home

One source of individual differences in numerical knowledge is the early home environment. In this section, we focus on the kinds of informal learning activities children engage in at home, variations in exposure to these activities, and consequences of these variations for children's developing numerical knowledge.

Number-related Activities and Parent-child Interactions

The number-related activities and support for learning that parents provide to children has been examined through self-reports, naturalistic observations in the home, and structured observations in the home and the laboratory. Questionnaires and interviews suggest that parents engage their young children in both formal and informal numerically relevant activities. These activities include formal teaching through number-related activity books and worksheets, explanations of number concepts, and practicing number skills, such as identifying written numbers (Huntsinger, Jose, Larson, Balsink Krieg, & Shaligram, 2000; Skwarchuk, 2009). Parents also engage their children in informal activities involving numbers, such as playing board games and card games, singing songs and nursery rhymes, and measuring ingredients while cooking (Blevins-Knabe & Musun-Miller, 1996).

Naturalistic observations indicate that parents begin exposing their children to numbers at a young age. In a longitudinal study with primarily middle-income families (Durkin, Shire, Riem, Crowther, & Rutter, 1986), parents were observed using number words with children as young as 9 months. Over the next 2 years, parents more frequently used number words and engaged their children in number-related activities, such as counting and reading books involving numbers. A more recent longitudinal study of parental input (Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010) found that variations in parent number talk is related to children's developing numerical knowledge. Families from diverse backgrounds were observed in their homes for five visits between the ages of 14 and 30 months. At 46 months, children were administered a measure of understanding of cardinality, in which children were shown two cards and asked to point to the one with a specific number (e.g. point to 6). The

amount of number talk that the parents engaged in from 14 to 30 months predicted their children's understanding of cardinality at 46 months, even after controlling for SES. A follow-up study revealed that particular types of number talk seemed better at promoting children's cardinality understanding. Specifically, parents' number talk involving counting or labelling the cardinal value of visible objects and their talk about large sets of objects were the most predictive of children's later number knowledge (Gunderson & Levine, 2011).

Studies using structured observations have indicated that the kinds of activities, materials, and games in which parents engage their children influences parental talk and support about numbers and numerical concepts. For example, Vandermaas-Peeler, Nelson, Bumpass, and Sassine (2009) asked parents to read a book with their children about a shopping trip, and then provided them with materials related to the story, such as pretend money and food, as well as cooking materials. They found that providing parents with these everyday materials elicited talk about the materials' general properties, such as appropriate uses for money, but elicited little talk about their numerical properties, such as the value of the money. In contrast, other studies using such methods have found that many parents engage their preschoolers in counting and other numerical activities, while reading books, playing with blocks, and working on a mathematical workbook. Materials that had fewer applications to daily life elicited greater talk about numbers (Anderson, 1997; Anderson, Anderson, & Shapiro, 2004).

Others have also found that different materials and contexts elicit different kinds of talk and support from parents. For example, Bjorklund, Hubertz, and Reubens (2004) observed parents and their preschoolers while they played a modified version of *Chutes and Ladders* together, and while they solved maths problems together. Parents were more likely to give cognitive directives, such as modelling the correct answer and providing instruction on strategies, when solving the maths problems, whereas they were more likely to use simple prompts when playing the board game.

Together, these findings suggest that parents engage in a variety of activities and discussions with their children that could support early numerical knowledge. Furthermore, the type of material influences parents' mathematically relevant interactions with their children.

Relations between Familial Numerical Activities and Early Maths Knowledge

Parents vary considerably in the frequency with which they engage in mathematically relevant activities with their children, and these variations influence children's developing numerical knowledge. Observational studies of the early home environment suggest that the absolute frequency with which parents engage their children in mathematical activities in the home tends to be quite low. For example, Tudge and Doucet (2004) conducted an observational study of preschool children from both White and Black families from diverse SES backgrounds. Children were observed during their daily routines for 18 hours, distributed over many days, in places such as home, childcare centers, and parks. On average, children were observed engaging in a mathematical lesson or play activity in less than 1 out of 180 observations.

One reason for this low absolute frequency is that parents tend to place a greater emphasis on literacy development than on mathematics development for their young children (Barbarin, Early, Clifford, Bryant, Frome, Burchinal, et al., 2008; Cannon & Ginsburg, 2008). Observations of homes and preschools, as well as reports of teachers and parents, suggest that the home and preschool environments provide children with fewer mathematical than literacy-orientated experiences (LeFevre, Skwarchuk, Smith-Chant, Fast, Kamawar, & Bisanz, 2009; Plewis, Mooney, & Creeser, 1990; Tizard & Hughes, 1984; Tudge & Doucet, 2004).

Although the average amount of mathematical activity is low, there is considerable variation in children's experience with number-related activities. For example, Levine et al. (2010), the quantity of number words that parents used varied from 4 to 257 words over the 7.5 hours of observation. As would be expected, children whose parents present them with more mathematical activities generally have greater mathematical knowledge and maths fluency. This relation is present for both amount of direct instruction and amount of informal learning activities involving numbers (Blevins-Knabe & Musun-Miller, 1996; Huntsinger et al., 2000; LeFevre et al., 2009). Frequency of engaging in non-mathematical informal learning activities at home also is predictive of subsequent maths achievement. Parents' reports of 3- and 4-year-olds' engagement in informal learning activities, such as rhyming and singing songs, as well as providing direct instruction about letters and numbers, predicts children's mathematical achievement at age 10 (Melhuish, Sylva, Sammons, Siraj-Blatchford, Taggart, Phan, M et al., 2008).

Differences in the mathematical knowledge of children from lower- and higher-income backgrounds also reflect differences in environmental support for maths learning. Lower SES families have numerous stressors, such as financial constraints and lower education, which can limit their ability to support their children's academic development (Rouse, Brooks-Gunn, & McLanahan, 2005). These factors likely influence SES-related differences in the types of resources and number-related activities parents report engaging in with their children at home. Interviews with parents of 2- and 4-year-olds revealed that middle-income parents reported engaging their children in numerical activities that were rated as higher in complexity than working class parents (Saxe et al., 1987). An example of a complex activity involved arithmetic operations and a simple activity involved songs involving numbers. Others also have found that parents of middle-class children report engaging their children in a wider range of number-related activities, and engaging in such activities more frequently, than families from lower-income backgrounds (Starkey et al., 2004; Starkey & Klein, 2008). However, even within lower-income families, the early home environment and the type of support they offer their children for preparing them for school vary greatly and in ways that influence their mathematics proficiency (Burchinal, McCartney, Steinberg, Crosnoe, Friedman, McLoyd, V. et al., 2011; Holloway, Rambaud, Fuller, & Eggers-Pierola, 1995). For example, within Head Start populations, children's numerical knowledge is positively related to the frequency of parents' engagement with them in both formal maths activities, such as practicing simple arithmetic, and

informal numerical activities, such as board games and card games (Ramani, Rowe, Eason, & Leech, 2013).

Thus, informal learning activities and the early home environment appear to play a critical role in the development of children's number skills. Having more opportunities for practicing number skills, through both informal learning activities and direct instruction, is positively related to children's maths skills.

Integrating Sociocultural Theory with a Theoretical Analysis of Numerical Sense

In this section, we discuss how we integrated the sociocultural orientation and research studies that followed from this orientation with a theoretical analysis of the mental number line, which is hypothesized to underlie children's number sense (e.g. Dehaene, 2011). Our goal was to understand individual differences in children's numerical magnitude knowledge and to identify ways of improving this understanding. We were interested in three specific questions:

1. How does numerical magnitude knowledge vary between children, especially children from different SES backgrounds.
2. What are the sources of these differences.
3. How can we promote young children's numerical magnitude knowledge?

Before discussing answers to these questions, however, we review research on the development of numerical magnitude knowledge and the importance of this knowledge for maths learning.

Representations of Numerical Magnitudes

Accurate estimation of numerical magnitudes is critical for mathematical achievement and is central to the concept of *number sense* (Berch, 2005; Siegler & Booth, 2005; Sowder, 1992). Estimation can involve approximating the answer to arithmetic problems (e.g. $124 + 272$), the distance between two objects or places (e.g. about how many miles is it to school), or the number of objects in a set (e.g. about how many cookies are in the jar?). Children with more advanced numerical estimation skills in first grade show faster growth in maths skills over the elementary school years, even after controlling for other predictive factors, such as intelligence and working memory (Geary 2011). Having a strong understanding of numerical magnitudes can lay the foundation for learning later, more complex, mathematics.

The cognitive structure thought to underlie numerical magnitude knowledge is the *mental number line*, which is based on the hypothesis that numbers are represented spatially on a continuum. In cultures that use left-to-right orthographies, numerical magnitudes increase from left to right on the continuum (Dehaene, 2011). Both behavioural and neural research indicates the importance of the mental number line (Ansari, 2008; Hubbard, Piazza, Pinel, & Dehaene, 2005). One body of evidence comes from research on the numerical magnitude task. Specifically, people more quickly answer 'Which is *bigger*, 8 or 3' when correct responses require pressing a key on the right rather than on the left. However, people more quickly answer 'Which is *smaller*, 8 or 3' by pressing a key on the left rather than on the right (Dehaene, Bossini, & Giraux, 1993). This spatial-numerical association of response codes (SNARC) effect provides evidence of how representations of quantities are ordered horizontally in a left to right array.

The form of mental number line representations can be measured using a number line estimation task. The number line estimation task involves presenting people lines with a number at each end (e.g. 0 and 100) and a third number, printed above the line, in that range. The task is to estimate the location of the third number on the line (e. g., 'Mark where 36 would go on the line'). There are three major benefits of the task.

1. The task can be used with any range of numbers, because any two numbers can be used at the ends of the lines.
2. Any type of number – whole, fraction, decimal, percentage, positive, negative – can be located on the line.
3. The number line task parallels the ratio characteristics of the number system.

That is, just as 60 is twice as large as 30, the distance of the estimated position of 60 from 0 should be twice as great as the distance of the estimated position of 30 from 0.

Performance on the number line estimation task correlates strongly with mathematics achievement test scores at all grade levels from kindergarten through eighth grade (Booth & Siegler, 2006; Geary, Hoard, Nugent, & Byrd Craven, 2008; Holloway & Ansari, 2009; Schneider, Grabner, & Paetsch, 2009; Siegler & Booth, 2004; Siegler, Thompson, & Schneider, 2011). Causal connections between number line estimation and maths learning also are present. Improving the numerical magnitude knowledge of children improves their learning of arithmetic and other mathematical skills (Booth & Siegler, 2008)

Numerical magnitude knowledge develops over several years and involves knowledge of a range of numerical skills and concepts. Knowledge of the counting sequence likely contributes to the development of numerical magnitude knowledge, but is not sufficient. Children count correctly from 1 at

least a year before they show much knowledge of numerical magnitudes in the same range or even know the rank order of those numbers (Le Corre, Brannon, Van de Walle, & Carey, 2006; Le Corre & Carey, 2007; Lipton & Spelke, 2005). For example, not until the age of 5 years do children's number line estimates become accurate and linear for the numbers 0–10, even though they can count to 10 at least a year earlier (Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010). Similarly, not until second grade do number line estimates become accurate for the numbers between 0 and 100, despite children being able to count to 100 a year or two earlier (Ebersbach, Luwel, Frick, Onghena, & Verschaffel, 2008; Geary et al., 2008; Siegler & Booth, 2004).

Variations in Numerical Magnitude Knowledge

To answer our first question of whether numerical magnitude knowledge varies between children from different SES backgrounds, we compared the performance of middle- and lower income preschoolers on a 0–10 number line estimation task (Siegler & Ramani, 2008). Children from lower-income backgrounds tended to have poorer numerical magnitude knowledge than children from middle-income backgrounds. Analyses of individual children's estimates showed the best fitting linear function accounted for a mean of 60% of the variance in the estimates of the individual children from middle-income backgrounds, but only 15% of the variance among children from low-income backgrounds.

Children from lower-income background also had a poorer understanding of the order of numbers. Specifically, we compared each child's estimate of the magnitude of each number with the child's estimate for each of the other numbers, and calculated the percentage of estimates that were correctly ordered. Children from higher-income backgrounds correctly ordered 81% of the estimates compared with 61% correct from the children from lower-income backgrounds.

Sources of SES-related Variations in Numerical Magnitude Knowledge

Our second question concerned potential sources of these SES-related differences in numerical magnitude knowledge. Based on the above review of the literature on the role of home activities in preschoolers' maths learning, informal activities seem to be critical for promoting early numerical knowledge. One common activity that seems ideally designed for producing linear representations of the mental number line is playing linear, numerical, board games – that is, board games with linearly-arranged, consecutively numbered, equal-sized spaces (e.g. *Chutes and Ladders*.) As noted by Siegler and Booth (2004), linear board games provide multiple cues to both the order of numbers and the numbers' magnitudes. Specifically, the greater the number in a square, the greater:

1. The distance the token from the origin to its present location.
2. The number of discrete moves the child has made.
3. The number of number names the child has spoken.
4. The number of number names the child has heard.
5. The amount of time since the game began.

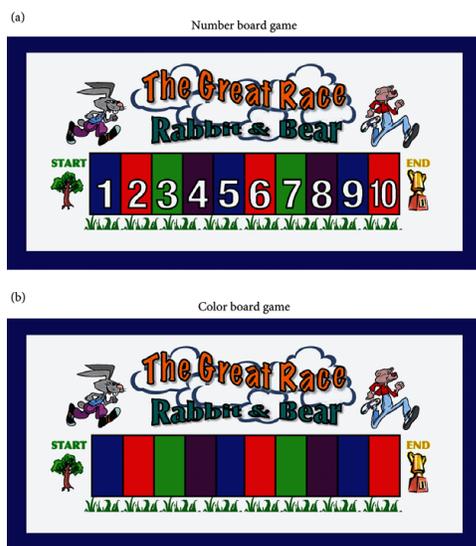
Thus, children playing the game have the opportunity to relate the number in each square to the time, distance, and number of manual and vocal actions required to reach that number. In other words, the linear relations between numerical magnitudes and these visuospatial, kinaesthetic, auditory, and temporal cues provide a broadly-based, multi-modal foundation for a linear representation of numerical magnitudes.

To test our hypothesis that such board games could account for SES-related differences in numerical knowledge, Ramani and Siegler (2008) asked young children from lower- and higher-income backgrounds directly about their experiences with board games at home – whether they play board games, card games, and video games at their own home and those of other friends and relatives, and which games they play. As predicted, more preschoolers from middle-income backgrounds reported playing board games and card games than children from low-income backgrounds. Specifically, 80% of the children from middle-income backgrounds reported playing board games at home or at other people's home, whereas only 47% of the children from low-income backgrounds did. A similar pattern was found for card games, but not for video games; 66% of the preschool children from lower-income backgrounds reported playing video games at home, whereas only 30% of the middle-income children did.

Children from low-income backgrounds who had more experience playing board games at their own and other people's homes exhibited greater numerical knowledge (Ramani & Siegler, 2008). The relationship was even present when only experience playing the single number board game *Chutes and Ladders* was considered. Reported experience playing card games and video games was not closely related to numerical knowledge, thus indicating that the correlations with board game experience were not due to numerically advanced children having better memory for their game playing experience or being more willing to report it.

Playing a Linear Number Board Game to Improve Numerical Magnitude Knowledge

To address our third question of how to improve the numerical knowledge of children from low-



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Figure 1. The (a) number and (b) colour linear board games (Ramani & Siegler, 2008; Siegler & Ramani 2008).

income backgrounds, Siegler and Ramani (2008) randomly assigned preschoolers from Head Start classrooms to either play a linear numerical board game with squares numbered from 1 to 10 or a colour board game that was identical, except for the squares varying in colours, rather than numbers (Figure 1).

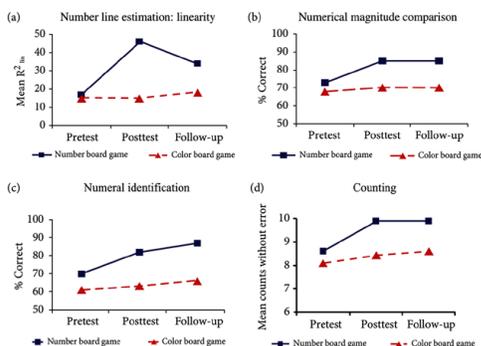
At the beginning of each session, children were told that, on each turn, they would spin a spinner with a '1' or '2' on it and move their token that number of spaces; the first person to reach the end would win. Children in the colour board condition were given the identical instructions, except their spinner varied in colour. The children were told to say the number (colour) on each space as they moved. For example, children who played the number board game who were on 3 and spun a 2 would say, '4, 5' as they moved their token. Similarly, children who played the colour board game who were on a red space and spun a purple, would say, 'green, purple', as they moved. Children played one of the two games one-on-one with an experimenter for four 15–20-minute sessions distributed over a 2-week period. Each game lasted approximately 2–4 minutes, so that children played their game roughly 20 times over the four sessions. Children estimated the positions of the numbers 1–10 on a number line prior to Session 1 as a pretest and at the end of Session 4 as a post-test.

Children who played the number board game considerably improved their numerical magnitude knowledge. On the pretest, the best-fitting linear function accounted for an average of 15% of the variance in individual children's estimates; on the post-test, it accounted for 61%. In contrast, for children in the colour board game condition, the best fitting linear function accounted for 18% of the variance on both pretest and posttest. Children who had played the numerical board game also ordered correctly the magnitudes of more numbers on the posttest than on the pretest. Peers who played an identical game, except for the squares varying in colour, rather than number, did not show comparable improvements on the task.

Improving Foundational Number Skills over Time

We then tested the generality of the benefits of playing the number board game across various number tasks and over time (Ramani & Siegler, 2008). Playing the linear board game provides children with practice at counting and at numeral identification, because players are required to name the squares through which they move (e.g. saying '6, 7' after starting on the 5 and spinning a 2). Thus, playing such games would be expected to improve counting and numeral identification skills, as well as performance on tasks that require understanding of numerical magnitudes. We also wanted to examine whether children's learning remained apparent many weeks after the last game playing session.

Ramani and Siegler (2008) presented 124 Head Start children several measures of numerical knowledge of the numbers 1–10. Children were given the number line estimation task, a magnitude comparison task ('Which is bigger: N or M?'), a numeral identification task ('Can you tell me the number on this card?'), and rote counting ('Count from one to 10'). These tasks were presented on a pretest before the game playing began in Session 1, on a post-test immediately after the final game was played in Session 4, and in a follow-up session 9 weeks after the post-test.



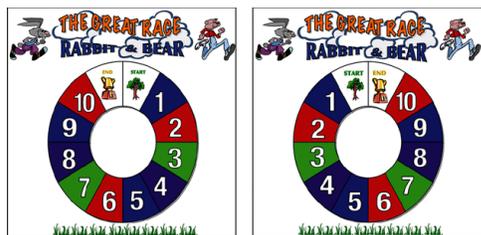
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Figure 2. Performance of preschoolers from low-income backgrounds on four numerical tasks: (A) number line estimation; (B) magnitude comparison; (C) numeral identification; and (D) counting, before playing the number or colour board game (pretest), immediately after the fourth and final session of playing the game (post-test), and 9 weeks after the final game playing session (follow-up) (Ramani & Siegler, 2008).

After playing the number board game, children showed improvements on all four measures of numerical knowledge. These improvements were stable over time. After 9 weeks of not having played the board game, improvements on all four tasks remained significant, and they were at least as large on three of the four tasks as on the immediate post-test (Figure 2). As in the previous study, children who played an identical game, except for the squares varying in color, did not show comparable improvements.

Identifying Important Features of the Board Game's Design

Testing the effects of specific features of the board game on children's learning is critical for understanding why the game works and for creating future informal learning activities. One feature that seemed likely to be important was how the linearity of the game board influenced children's learning about numerical magnitudes. To test this feature, Siegler and Ramani (2009) assigned children to play either the linear board game or a circular board game (Figure 3). The linear game was expected to be more effective than the circular one on the magnitude tasks (number line and magnitude comparison), because the linear board is easier to translate into a linear mental number line. There was no obvious reason to predict that the linear board would promote greater improvement than the circular board in numeral identification because that skill does not depend in any obvious way on a linear representation. Instead, the linear board and the circular board were



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Figure 3 . The circular number board games (Siegler & Ramani, 2009; Ramani & Siegler, 2011)

expected to be equally effective in promoting numeral identification skills.

As predicted, playing the linear board game for roughly an hour increased low-income preschoolers' proficiency on numerical magnitude comparison and number line estimation. Playing the game with the circular boards did not improve children's performance on these measures. Also as predicted, playing the linear and circular board games improved children's numeral identification skills by an equal amount. Counting was at ceiling in this sample, so no comparisons were possible.

Another major finding of Siegler and Ramani (2009) was that preschoolers who earlier had played the linear board game learned more from subsequent training on arithmetic problems than peers who had played the linear board game. We predicted that learning answers to arithmetic problems in part reflects appropriate numerical magnitude representations, and that playing the

linear board game produces such representations. During the pretest and post-test, children were administered four simple arithmetic problems, $2 + 1$, $2 + 2$, $4 + 2$, and $2 + 3$. After playing the board game for the four sessions, in a fifth session children were given a brief training with feedback on the two easiest arithmetic problems that they answered incorrectly on the pretest. Then they were asked to answer the two problems without feedback. Among children who had previously played the linear numerical board game, the percentage of correct addition answers was higher than in the circular board game condition or in a control condition. Especially relevant to the idea that the gains came about through improving children's numerical magnitude representations, children's errors in the linear board condition, but not in the circular board condition, tended to become closer to the correct answer from pretest to post-test.

A second feature of the board game that we tested was whether the context of the game was important for promoting children's numerical knowledge. To determine whether playing numerical board games had effects above and beyond those of common number activities, Siegler and Ramani (2009) provided a third group of children practice with counting and numeral naming tasks, but not in a game context. We found that having children engage in a continuing cycle of the tasks – number string counting, numeral identification, and object counting – for the same length of time as children played the board game did not influence children's numerical knowledge. These children also did not improve their ability to learn the answers to novel arithmetic problems.

Scaling Up the Board Game Intervention

Determining whether an intervention can be used in everyday settings requires evidence beyond that the intervention is effective under controlled, laboratory conditions. Three types of evidence relevant to the present context are whether the board game is effective with different populations, when played with small groups of children, and when implemented by a paraprofessional from the children's classroom.

One variable that is important for scaling up the intervention is whether children from some groups benefit more than others. Preschoolers from low-income backgrounds at times show greater gains from mathematical interventions than preschoolers from middle-income backgrounds (Starkey et al., 2004). Because children from middle-income backgrounds have greater prior board game experience than children from low-income backgrounds, this greater experience might make playing the present board game redundant with the middle-income children's prior experience, and thus less effective for improving their numerical knowledge. We tested whether playing the linear board game would improve the numerical knowledge of preschoolers from middle-income backgrounds, or whether the benefits were unique to children from low-income backgrounds. Specifically, we compared the relative benefits of playing a linear number board game for two groups of children who before the experience had equal numerical knowledge: 3- and 4-year-olds from middle-income backgrounds and 4- and 5-year-olds from low-income backgrounds.

Children from low-income backgrounds learned at least as much, and on several measures more, than preschoolers from middle-income backgrounds with comparable initial knowledge. Within each group, children who initially knew less tended to learn more. Overall, the findings suggest that playing the linear board game is effective at promoting the numerical knowledge of children from both lower- and middle-SES backgrounds.

Interventions that are effective in lab settings are often ineffective in classrooms (Newcombe, Ambady, Eccles, Gomez, Klahr, Linn, M. et al., 2009; White, Frishkoff, & Bullock, 2008). Two likely reasons are that the 1:1 experimenter–child interactions that are typical of laboratory studies are often impossible in classrooms, and that the people executing the intervention in classrooms usually have fewer opportunities for training in executing the interventions than research personnel.

To better understand these challenges, we have begun to examine whether the number board game could be translated into a practical classroom activity that improves Head Start children's numerical knowledge. Participants within a condition were randomly divided into groups of three children and were presented six 20–25-min sessions within a 3- or 4-week period. Children played a similar linear number board game or colour board game to those used in previous studies. The procedures and game playing were also similar except the children played the game with each other, and the experimenter facilitated the game, instead of playing.

Playing the number board game as a small group learning activity promoted low-income children's number line estimation, magnitude comparison, numeral identification, and counting. Children who played the colour board game only improved in counting skills.

Improvements were also found when paraprofessionals from the children's classrooms played the game with small groups of children. The paraprofessionals were given roughly an hour of training prior to the start of the study. During this time, they were given the board game materials and an opportunity to practice with them. They were also given a short booklet that included the rules for the number and colour games, scripts for how to explain the games to the children, and standard prompts for correcting errors. The paraprofessionals also watched a demonstration video of a group of children playing the board games, and were told to correct errors or omissions by prompting children to say the required number or colour. If the errors continued, the paraprofessionals were to model the correct move and ask the child to repeat the move.

We found that playing the number board game as a small group activity supervised by a paraprofessional from the classroom improved children's numerical knowledge on four measures. Observations of the game playing sessions revealed that paraprofessionals adapted the feedback they provided to reflect individual children's improving numerical knowledge over the game playing sessions and that children remained engaged in the board game play even after multiple sessions (Ramani, Siegler, & Hitti, 2012). Thus, the linear number board game can be used to promote the numerical knowledge of children from a range of SES backgrounds and can be used effectively in preschool classrooms.

Preschool Mathematics Interventions and Curricula

Other targeted interventions also have been shown to be effective in improving young children's numerical understanding. An adaptive software program called 'The Number Race,' aimed at improving young children's number sense, has improved the skills of children with mathematical difficulties (Wilson, Revkin, Cohen, Cohen, & Dehaene, 2006; Wilson, Dehaene, Dubois, & Fayol, 2009). Other experimental interventions that have incorporated number board games have also produced improvements in young children's numerical knowledge (e.g. Malofeeva, Day, Saco, Young, & Cianco, 2004).

More comprehensive curricula for improving low-income preschoolers' and kindergartners' mathematical knowledge have also shown large positive effects. These programmes integrate informal learning activities with direct classroom instruction. One such curriculum is *Number Worlds*, which includes a wide range of numerical activities – songs about numbers, counting games, games involving money, and board games. The goal of the curriculum is to provide children with a strong foundation with numbers before teaching them more advanced concepts. Researchers have found that following participation in the *Number Worlds* curriculum, low-income kindergartners had significantly better basic numerical skills than peers who did not receive the curriculum (Griffin, 2004).

Another early childhood curriculum, *Pre-K Mathematics*, combines school- and home-based activities to promote children's numerical knowledge. Children participate in small-group activities in the classrooms and parents are also provided with activities to do at home that link to the small-group activities in the school. Participation in the programme led to kindergartners from low-income backgrounds having mathematical knowledge at the end of the programme equivalent to that of middle-income peers who did not participate in it (Starkey et al., 2004).

Similarly, the *Building Blocks* curriculum (Clements & Sarama, 2007) includes classroom activities, with small group activities and computer games. Randomized control trials of preschoolers from low-income backgrounds indicated that children given the *Building Blocks* curriculum made much greater progress than a control group in number, geometry, measurement, and recognition of patterns. Overall, these curricula have found success by combining direct instruction, home involvement, and informal learning activities as ways to promote the numerical knowledge of young children.

Conclusions

The early home environment and children's experiences with informal learning activities play a critical role in mathematical development. Understanding that these experiences contribute to individual differences in numerical knowledge helped to inform the design of an intervention that can be used to promote the numerical knowledge of young children from lower-income backgrounds. A large body of evidence, including our research on board games, provides good reason to advocate that parents and teachers more frequently engage preschoolers in mathematical activities. This evidence includes the finding that early numerical knowledge lays the groundwork for later mathematical achievement, and that young children's number skills can be improved through a variety of informal and formal numerical activities. Many of these activities, including the linear number board game, are inexpensive or can be created at home, and require minimal time to play. Thus, it seems critical to play such games, engage in other informal maths activities, and make available mathematics curricula of proven effectiveness to a wider range of preschoolers, especially preschoolers from low-income backgrounds.

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