Reducing the gap in numerical knowledge between low- and middle-income preschoolers

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A R T I C L E   I N F O

Article history:
Received 13 May 2010
Received in revised form 20 October 2010
Accepted 9 February 2011
Available online 3 April 2011

Keywords:
Math
Number
Preschoolers
Arithmetic
Interventions
Board games

A B S T R A C T

We compared the learning from playing a linear number board game of preschoolers from middle-income backgrounds to the learning of preschoolers from low-income backgrounds. Playing this game produced greater learning by both groups than engaging in other numerical activities for the same amount of time. The benefits were present on number line estimation, magnitude comparison, numeral identification, and arithmetic learning. Children with less initial knowledge generally learned more, and 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. The findings suggest a class of intervention that might be especially effective for reducing the gap between low-income and middle-income children's knowledge when they enter school.

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When formal schooling begins, children already differ greatly in mathematical knowledge. These early differences predict long-term outcomes: Kindergartners' mathematical knowledge predicts their math achievement test scores in first grade, third grade, fifth grade, eighth grade, and even high school (Duncan et al., 2007; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Stevenson & Newman, 1986). Perhaps because of the hierarchical structure of mathematics, the strength of these predictive relations is much greater in math than in other, less hierarchical, domains. For example, the relation between early and later mathematics achievement is more than twice as large as the relations between the earliest and last reading achievement, attention deployment, and emotional control (Duncan et al., 2007).

The strong relation between early and later mathematical knowledge is one factor that has led to calls for improving early childhood mathematics education by both researchers (Clements & Sarama, 2007; Ginsburg, Lee, & Boyd, 2008; Griffin, 2007; Starkey, Klein, & Wakeley, 2004) and national commissions (National Council of Teachers of Mathematics, 2006; National Mathematics Advisory Panel, 2008; National Research Council, 2009). Another factor that has contributed to these recommendations is the presence of a sizeable gap between the mathematical knowledge of children from low-income and middle-income backgrounds. This gap is present before children enter elementary school, and it progressively widens over the course of schooling (Case & Okamoto, 1996; Denton & West, 2002; Geary, 2006). Improving the mathematical knowledge with which children from low-income backgrounds begin school may produce lasting benefits by making school-based mathematics instruction more comprehensible, and thus more motivating, for children from low-income backgrounds.

One approach to improving the numerical knowledge of children from low-income backgrounds before they begin formal schooling involves playing linear numerical board games (Siegler & Ramani, 2008). Playing linear numerical board games—that is, board games with linearly arranged, consecutively numbered, equal-size spaces (e.g., Chutes and Ladders) provides multiple, redundant cues to the numbers’ magnitudes. For example, in the first row of Chutes and Ladders (the row from 1 to 10), the greater the number in a square, the greater: a) the number of discrete movements of the token that the child has made, b) the number of number names that the child has said and heard, c) the distance that the child has moved the token, and d) the amount of time that has passed since the game began. The linear relations between numerical magnitudes and these kinesthetic, auditory, visuo-spatial, and temporal cues provide a broadly based, multi-modal, embodied foundation for a linear representation of numerical magnitudes. Such redundant, multisensory cues are helpful for learning numerical relations even in infancy (Jordan, Suanda, & Brannon, 2008). From another perspective, linear numerical board games provide physical realizations of the mental number line, which has been hypothesized to be the central conceptual structure underlying numerical understanding (e.g., Case & Okamoto, 1996). Linear number board games also provide children with practice at
counting and at numeral identification and thus seem likely to improve those essential skills.

Board games other than Chutes and Ladders also provide children with useful cues to numerical magnitude and practice in counting. For example, in many board games, children roll dice, translate the dots that face up into a number, and use the number to determine how far to move their token. This allows them to correlate the number with the distance they move the token, the number of distinct moves they make, the number of number words they say and hear, and the time it takes to move the token to the square with that number. Board games with spinners allow children to extract the same correlations.

Studies examining the effects of playing board games with low-income preschoolers have lent credence to this analysis. In Ramani and Siegler (2008) and Siegler and Ramani (2008), preschoolers from low-income backgrounds played either a linear numerical board game with squares numbered from 1 to 10 in a row extending from left to right, or a game that was identical except that the squares varied in color but not number. After four 15–20 minute sessions, the children who played the numerical version of the game showed greater improvements on several foundational numerical skills: counting, numeral identification, magnitude comparison, and number line estimation. These improvements were stable over at least a nine-week period (Ramani & Siegler, 2008) and have been replicated in Great Britain (Whyte & Bull, 2008).

The dramatic improvement in the numerical knowledge of preschoolers from low-income backgrounds raises a question about the generality of the board game's effects. Would children from higher SES backgrounds benefit differently from playing the board game? This question has important implications for interventions that could be used and are most effective to promote the mathematical knowledge of preschoolers from both lower- and middle-income backgrounds.

One reason that there may be differences in the benefits of playing the board game is because a likely source of the gap in numerical knowledge between low- and middle-income children is from differences in the types and frequency of informal activities in which they engage in outside of preschool and daycare. As discussed earlier, everyday, informal activities like board games provide children with extensive numerical information and in experimental settings can effectively promote numerical knowledge. These informal activities and games can also contribute to early numerical development in the home environment (Saxe, 2004). With kindergartners through second graders, frequency of engaging in board games, card games, and cooking by following recipes at home is positively related to children's numerical skills (Lefevre et al., 2009). Engaging in other types of informal learning activities at home before children enter school also can have positive long-term effects on achievement. Parents' reports of engagement in informal learning activities at age 3 to 4, 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 et al., 2008).

Children from middle-income backgrounds tend to have more experience with informal learning activities such as board games, including ones with explicitly numerical content such as “Chutes and Ladders,” than children from low-income backgrounds. In Ramani and Siegler (2008), twice as many preschoolers from middle-income backgrounds as peers from low-income backgrounds reported playing board games outside of preschool. These findings were not attributable to children from low-income backgrounds being less willing to report their game playing experience or remembering such experience less well; the same children from low-income families reported more experience playing video games than their peers from middle-income backgrounds. A larger percentage of the children reported playing action and adventure video games as opposed to educational video games, which are designed to promote learning and can have some cognitive benefits for children (Din & Calao, 2001; Subrahmanyan & Greenfield, 1996). Moreover, the complexity of informal numerical activities in which middle-income parents report engaging with their children is greater than the complexity of numerical activities reported by low-income parents (Saxe, Guberman, & Gearheard, 1987).

Although experiences that benefit children from low-income backgrounds tend to benefit children from middle-income backgrounds, there was reason to question whether that would be the case in the present context. Prior research has shown that preschoolers from low-income backgrounds show greater gains from mathematical interventions than preschoolers from middle-income backgrounds (Starkey et al., 2004). This pattern of learning may also occur from playing the linear board game. 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 ineffective or less effective for improving their numerical knowledge.

The present study addresses two questions about the generality of the board game's effects. First, does playing the linear number board game improve the numerical knowledge of preschoolers from middle-income backgrounds, or is the benefit unique to children from low-income backgrounds? Second, if playing the game does improve the numerical knowledge of preschoolers from middle-income families, are the gains greater than, less than, or equal to those of preschoolers from low-income families with similar initial knowledge about numbers? These two questions were examined in Experiments 1 and 2, respectively.

**Experiment 1**

The main goal of Experiment 1 was to test whether playing a linear number board game improved the numerical knowledge of 3- and 4-year-old preschoolers from middle- and upper-middle-income backgrounds. The study paralleled Siegler and Ramani (2009) except for the population studied. One major finding from that earlier study was that playing a linear board game with preschoolers from low-income families produced greater learning than playing a circular number board game or engaging in other types of numerical activities with them. The greater effectiveness of the linear game relative to the circular one was predicted on the logic that linear representations of quantitative dimensions are easier to form than non-linear ones, and the linear board is easier to translate to a linear representation.

Another major finding from Siegler and Ramani (2009) was that preschoolers who earlier played the linear board game learned more from subsequent practice and feedback on addition problems than peers in the other two conditions. This was predicted on the logic that playing the linear board game produces cognitive representations that maintain equal spacing throughout the number range, which would help in discriminating answers to arithmetic problems. Experiment 1 tested whether playing the linear board game had similar effects on preschoolers from more affluent backgrounds.

As noted previously, children from middle-income backgrounds generally have more advanced numerical knowledge than children from low-income backgrounds. Starkey et al. (2004) found a gap in numerical knowledge of more than seven months between 4-year-olds from lower and middle-income families. Our own pilot testing indicated a difference of approximately eight months between the numerical knowledge of 4-year-olds from low- and middle-income families. Therefore, to obtain a sample with equivalent prior numerical knowledge as in Siegler and Ramani (2009), we recruited children from middle-income backgrounds who were eight months younger, on average, than those in the low-income sample.

A second goal was to determine whether younger and older preschool children benefit from playing the linear board game. This...
would provide insight into the most suitable age range for benefiting from playing the board game. Because the middle-income children were much younger than the children previously examined, it was possible that they would not learn as much from playing the board game. The reason is that younger children often learn mathematics more slowly than older children (Geary, 2006). Another possibility, however, was that playing the linear board game would be beneficial for younger, middle-income preschoolers, just as it had previously been found to be for older children from low-income backgrounds.

A third goal of Experiment 1 was to examine individual differences in learning from the linear board game among children with more and less prior knowledge. Siegler and Ramani (2009) found that children with lower initial knowledge learned more from the board game, thus narrowing the gap between them and their peers. This pattern is the opposite of the well-documented Matthew Effect (Merton, 1968; Stanovich, 1986, 2000), named for a Biblical passage observing that the rich tend to get richer and the poor tend to get poorer. In psychological contexts, the Matthew Effect refers to such phenomena as initial reading proficiency being positively correlated with gains over grades in reading achievement test scores, initial IQ being positively related to changes over grades in mental age, initial mathematical knowledge being positively correlated with increases over grades in math achievement test scores, and so on (Geary, 2006; Morgan, Farkas, & Hibel, 2008; Shaywitz, Holford, & Holahan, 1995; Stanovich, 2000).

The data in Siegler and Ramani (2009) were in the opposite direction from this pattern. The greater learning of children with less initial numerical knowledge was not attributable to unreliability of the measures or regression to the mean. Pretest–posttest correlations were very high on all measures in all three conditions, most exceeding \( r = .80 \), and there was no narrowing of the pretest gap between less and more knowledgeable children in the one experimental condition that did not produce learning. This reverse Matthew Effect was unexpected, and it seemed important to replicate it and extend it to another population before trying to explain it.

A fourth goal of Experiment 1 was to determine whether playing a circular board game improves the numerical magnitude understanding of children from middle-income backgrounds. The children from low-income families in Siegler and Ramani (2009) derived little benefit from playing the circular game, showing significant gains only on the numeral identification measure. The lack of any learning among children who played the circular board game on the two tasks that measured numerical magnitude understanding, number line estimation and numerical magnitude comparison, was surprising, because the circular game provided the same auditory, temporal, and kinesthetic cues that were hypothesized to lead to learning from the linear game. The lack of a linear visual cue to distance traveled was expected to lead to less learning of numerical magnitudes among children who played the circular game, but the lack of any learning was not expected. Again, replicating this finding seemed important given that not all board games are linearly arranged; designs of future educationally-oriented board games could benefit from information regarding the effects of different spatial layouts.

Children within each preschool were randomly assigned to one of three conditions: The linear board game condition, the circular board game condition, or the numerical activities control condition. The linear board game condition included 30 children \( M = 4 \) years, 0 months, \( SD = .32 \), 60% female, 70% Caucasian, 30% Other [Asian, Hispanic, Biracial, or Unknown]; The circular board game condition included 29 children \( M = 4 \) years, 0 months, \( SD = .38 \), 66% female, 72% Caucasian, 28% Other. The numerical activities control condition included 29 children \( M = 4 \) years, 0 months, \( SD = .40 \), 59% female, 86% Caucasian, 14% Other. The experimenters were a female of Indian descent (the first author) and two female, Caucasian, research assistants, who were blind to the specific hypotheses of the study.

Each preschooler met individually with an experimenter for five 15–20 minute sessions within a three-week period. A given child interacted with the same experimenter in all sessions. Each experimenter worked with approximately equal numbers of children in each condition. Sessions were held in either the children’s classroom or an unoccupied room nearby.

**Procedure, experimental conditions and materials**

*Overview.* Children participated in five sessions. In Session 1, children were given five pretest tasks: Number line estimation, magnitude comparison, counting, numeral identification, and addition problems. At the end of Session 1, throughout Sessions 2 and 3, and at the beginning of Session 4, children engaged in the training procedure of the experimental condition to which they were assigned. At the end of Session 4, all children were presented four of the five tasks that they had performed on the pretest (all but the addition problems). In Session 5, all children were presented the arithmetic learning procedure of addition problems, followed by a posttest with addition problems identical to the problems presented at pretest in Session 1.

**Linear board game condition.** The board used in the linear board game condition was 52 cm wide and 24 cm high. It included 10 different colored squares of equal size, arranged in a horizontal array. Each square contained one number, with the numbers increasing consecutively from left to right. The game also included a spinner with a “1” half and a “2” half, as well as a “bear token” and a “rabbit token.” Children chose the bear or the rabbit token before each session to represent their progress on the board; the experimenter took the remaining token. Due to children almost always choosing to go first, they won most games.

At the beginning of each session, the experimenter told the child that they would take turns spinning the spinner and that whoever reached the end first would win. Then the experimenter said that on each turn, the player who spun the spinner would move her or his token the number of spaces indicated on the spinner. The experimenter also told the child to say the numbers on the spaces through which the token moved. Thus, children who were on the square with a 3 and spun a 2 would say, “4, 5” as they moved. If a child erred or could not name the numbers, the experimenter correctly named them and then had the child repeat the numbers while moving the token (see Siegler & Ramani, 2009 for details about the board game play). Preschoolers either played the linear game, or the circular game described below approximately 20 times over the four sessions, with each game lasting 2–3 min.

**Circular board game condition.** The only difference between the linear and circular conditions involved the game boards. There were two circular boards, each divided into 12 wedges. Both boards were 38 cm high and 41 cm wide. Ten of the wedges, those located approximately at the locations of 2:00 through 10:00 on an analog clock, included the numbers 1–10 ordered consecutively. On one board, the numbers increased clockwise; on the other, the numbers increased counterclockwise.
The procedure followed in the circular board condition was identical to that in the linear board condition. Half of the children in this condition played the clockwise version of the game \((n = 14)\), and the other half played the counterclockwise version \((n = 15)\). The number of games played and time spent playing did not differ between the linear and circular board conditions.

**Numerical activities control condition.** Preschoolers in the numerical activities control condition were presented three tasks in a continuing cycle: Number string counting, numeral identification, and object counting. Whichever activity would have been next at the end of one session was first at the following session. On the object counting task, children were asked to count a row of between 1 and 10 poker chips, with the exact number varying randomly. The procedures for the other two tasks, number string counting and numeral identification, were the same as those used to assess those skills on the pretest and posttest, described in the next section.

To equate the amounts of time participating in the three conditions, each child in the numerical activities control condition was paired with a child of the same age (within 2 months) in a board game condition, and the length of each session was matched. Thus, if a child in a board game condition played the game for 16 min in Session 2, the paired child in the numerical activities control condition also engaged in numerical activities for 16 min in Session 2. As in the other conditions, general praise and encouragement were presented periodically, but no specific feedback regarding correctness was presented.

**Measures**

**Counting.** Children were asked to count from 1 to 10. Counting was coded as correct up to the first error (e.g., if a child counted “1, 2, 3, 4, 5, 6, 8, 9, 10,” her score was 6).

**Number line estimation.** Children were presented 18 sheets of paper, one at a time. Each sheet was a 25 cm line, with “0” just below the left end, and “10” just below the right end. A number from 1 to 9 inclusive was printed approximately 2 cm above the center of the line, with each number printed on 2 of the 18 sheets. All numbers from 1 to 9 were presented once before any number was presented twice; the nine numbers were ordered randomly both times. Children were told that they would be playing a game in which they needed to mark the location of a number on a line. On each trial, after asking the child to identify the number at the top of the page (and helping if needed), the experimenter asked, “If this is where 0 goes (pointing) and this is where 10 goes (pointing), where does N go?”.

**Numerical magnitude comparison.** Children were presented a 20-page booklet. Each page displayed two numbers between 1 and 9 inclusive; children were asked to choose the bigger one. The experimenter first presented 2 example problems with feedback, followed by 18 experimental problems without feedback. The 18 experimental problems were a randomly chosen half of the 36 possible pairs. On the warm-up problems, the experimenter pointed to each number and asked (e.g., “John (Jane) had one cookie and Andy (Sarah) had six cookies. Which is more: One cookie or six cookies?” On the two practice problems, the experimenter corrected any errors that were made. On the 18 experimental problems, half of the children within each condition were presented a given pair in one order and half in the opposite order.

**Numerical identification.** The task involved 10 randomly ordered cards, each with a numeral from 1 to 10 on it. On each trial, the experimenter held up a card and asked the child to name the numeral.

**Arithmetic problems and training.** The arithmetic pretest was composed of four addition problems, presented in the order: \(2 + 1, 2 + 2, 4 + 2, \text{and } 2 + 3\). Children were asked, “Suppose you have N oranges and I give you M more; how many oranges would you have then?” As on the other pretest and posttest tasks, no feedback was given.

One goal of the study was to examine whether playing the linear board game improved children’s ability to learn the answers to addition problems. To test whether the game produced this effect, at the beginning of Session 5, children received training on the first two arithmetic problems that they answered incorrectly on the pretest. The training involved presenting the two problems and their answers three times in alternating order. For example, children who erred on all four problems on the pretest were presented \(2 + 1\) and \(2 + 2\) in the first cycle of Session 5, \(2 + 2\) and \(2 + 1\) in the second cycle, and \(2 + 1\) and \(2 + 2\) in the third cycle. The problems were presented in the same “oranges” context as on the pretest. Children needed to answer each problem within 5 s; if they failed to do this, they were prompted to answer. On each trial, after children stated their answer, they were asked to explain how they obtained that answer. Then, they were given feedback and told the right answer. The children’s explanations indicated that on almost all trials (96%), they retrieved the answer from memory or guessed. After the third cycle of feedback problems, children received the addition posttest, in which they were presented the same four problems in the same order as on the pretest and asked to state the answer.

**Results**

Preliminary analyses were conducted to confirm that there were no experimenter administration effects. These analyses indicated that there were no differences in the pretest and posttest performance of the children due to differences among experimenters; therefore, all analyses were conducted on data collapsed over experimenters. Preliminary analyses comparing the pretest and posttest performance of children who played the clockwise and the counterclockwise circular boards also indicated no differences on any measure. Therefore, no distinction between the two circular boards was made in further analyses.

**Effects of experimental conditions**

We first examined multivariate effects of experimental condition, age, and session across number line estimation, magnitude comparison, counting, and numeral identification tasks. We did not include arithmetic performance in this analysis, because the MANOVA was intended to measure direct effects of playing the board games, and arithmetic posttest performance reflected subsequent feedback experience with the addition problems.

The measure examined for the magnitude comparison and numeral identification tasks was number of correct answers. The measure examined for the counting task was number of numbers counted before the first error. Two measures were examined for the number line estimation task – linearity and slope – because they provide different information. On the number line task, the ideal function relating actual and estimated magnitudes on the number line test is \(y = x\), an estimation pattern that is perfectly linear (\(\text{lin} = 1.00\)) with a slope of 1.00. However, estimates can increase in a perfectly linear function with a slope less than 1.00, and estimates can increase with a slope of 1.00 but not fit a linear function very closely. To examine the age variable, a median split was used to identify a younger group of 40 children \((M = 3\text{ years 9 months, }SD = .19, \text{ range } = 3\text{ years 5 months to 3 years 11 months})\), and an older group of 48 children \((M = 4\text{ years 3 months, }SD = .18, \text{ range } = 4\text{ years 0 month to 4 years 8 months})\).

A 2 (age: Below or above median) \(\times\) 3 (condition: Linear board, circular board, or numerical activities control) \(\times\) 2 (session: Pretest or posttest) repeated measures multivariate analysis of variance (MANOVA) revealed effects of age, \(F(5, 78) = 3.31, p = .01, \eta_g^2 = .18,\) and
session, \(F(5, 78) = 3.39, p < .01, \eta^2_p = .18\), and also a condition by session interaction, \(F(10, 156) = 2.57, p < .01, \eta^2_p = .14\). To examine the consistency of results across tasks, and to better understand the interaction, univariate analyses were conducted for each task.

**Number line estimation**

Linearity of number line estimates was the measure that most directly corresponded to the construct of a linear representation of numerical magnitude. The linearity of individual children's number line estimates varied with age, \(F(1, 82) = 5.04, p < .05, \eta^2_p = .06\), and session, \(F(1, 82) = 5.69, p < .05, \eta^2_p = .07\). The main effect for age indicated that across conditions and sessions, older preschoolers' estimates were more linear than those of younger preschoolers, mean \(R^2_{lin} = .36\) versus .21.

The main effect of session indicated that linearity increased from pretest to posttest, \(R^2_{lin} = .26\) versus .31. To further understand this main effect, we conducted t-tests to examine where there were differences between conditions in improvement from pretest to posttest. As shown in Fig. 1, among children who played the linear board game, the mean percent variance in individual children's estimates that was accounted for by the best fitting linear function increased from 26% on the pretest to 36% on the posttest, \(t(29) = 2.57, p < .05, \delta = .28\). In contrast, no significant changes were present among children who played the circular board games (25% vs. 30%) or engaged in the numerical activities control condition (29% vs. 29%).

The slopes of the number line estimates varied with age, \(F(1, 82) = 5.10, p < .05, \eta^2_p = .06\), and with the condition by session interaction, \(F(2, 82) = 5.53, p < .01, \eta^2_p = .12\). The best fitting functions for the older preschoolers' estimates had higher slopes than the best fitting functions for the estimates of their younger peers, mean slope = .43 vs. .23. The interaction between condition and session again resulted from larger gains among children who played the linear board game than among children in the other two conditions. Among children who played the linear board game, the mean slope of number line estimates increased from pretest to posttest, 32 versus .46, \(t(29) = 2.86, p < .01, \delta = .29\). In contrast, pretest–posttest changes in slope were not significant among children who played the circular board game, .27 and .33, or among children in the numerical control condition, .36 and .30.

**Numerical magnitude comparison**

Number of correct magnitude comparisons varied only with age, \(F(1, 82) = 16.51, p < .001, \eta^2_p = .17\). Older preschoolers were more accurate than younger preschoolers, 87% vs. 72% correct.

**Numerical identification**

Number of correct numeral identifications varied with age, \(F(1, 82) = 4.17, p < .05, \eta^2_p = .05\), and session, \(F(1, 82) = 8.92, p < .01, \eta^2_p = .10\). Older preschoolers correctly identified more numbers (8.2 vs. 7.2), and children generated more correct answers on the posttest than on the pretest (7.9 vs. 7.5).

The main effect of session indicated that numeral identification increased from pretest to posttest, \(R^2_{fi} = .26\) versus .31. Children who played the linear board game improved from a mean of 7.5 correct identifications on the pretest to 8.1 correct identifications on the posttest, \(t(29) = 2.63, p < .05, \delta = .24\). Children who played the circular board games improved from 7.3 to 7.9 correct identifications from pretest to posttest, \(t(28) = 2.39, p < .05, \delta = .24\). In contrast, the numeral identification skills of children in the numerical control condition did not improve: 7.9 correct on both the pretest and the posttest.

**Counting**

Due to ceiling effects, no meaningful analysis of counting performance could be conducted. Counting performance was perfect for 91% of children on the pretest and 93% of children on the posttest.

**Arithmetic**

In analyzing the arithmetic data, we examined both number of correct answers and absolute error (the absolute value of the distance of the child's response from the sum). These analyses were limited to

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**Fig. 1.** Pretest and posttest performance among middle-income children in linear board game, circular board game, and numerical control activities conditions.
the two items on which each child received training. Four children were excluded from the analyses because they answered all four problems correctly at pretest. Fourteen other children answered three of the addition problems correctly on the pretest. Their arithmetic training session included the one problem they answered incorrectly and one problem they answered correctly on the pretest. Only the item that they answered incorrectly was included in the statistical analysis.

Children answered somewhat more addition problems correctly after playing the linear or the circular board game than did children who earlier had engaged in the numerical control activities (38% and 46% correct vs. 28% correct). The differences, however, were not significant. Mean absolute error on the arithmetic problems decreased significantly (i.e., answers became more accurate) from pretest to posttest for children who earlier had played the linear board game, 2.0 versus 1.3, t(29) = 2.49, p < .05, d = .59, and for children who earlier had played the circular board game, 1.8 versus .94, t(26) = 3.39, p < .01, d = .91. There was no change in absolute error among those who had engaged in the numerical control activities (mean error = 2.0 and 1.9 at pretest and posttest).

**Individual differences**

**Consistency over sessions.** Pretest–posttest correlations of performance within each condition indicated that individual differences were very stable on number line linearity, number line slope, magnitude comparison, and numeral identification with correlations ranging from r = .82 to r = .89, ps < .001 in all three conditions. Arithmetic performance was far less stable, probably because the underlying data included answers to only the two trained problems, with correlations ranging from r = .07 to r = .33. ns Ceiling effects compromised correlations involving counting, which therefore were not computed. The stability of individual differences from pretest to posttest on the other four measures indicated that those measures of numerical knowledge are highly reliable.

**Relations across tasks.** Correlations were computed to examine whether consistent individual differences were present across the different numerical tasks. As shown in Table 1, significant correlations were present at both pretest and posttest for all direct measures of magnitude knowledge: Number line estimation, number line slope, and magnitude comparison. All of these measures were also positively correlated with numeral identification skill at both pretest and posttest. The correlations to arithmetic absolute error were weaker and less consistent, probably because the arithmetic data were based on answers to only the two problems on which children received training. Overall, the correlations across tasks were not as strong as those between performance on the same task at pretest and posttest, but they indicated some commonality across tasks in numerical knowledge.

**Existing knowledge and acquisition of new knowledge**

We divided children in the linear board game condition, the condition that produced the greatest gains, into those with pretest performance above and below the median on each task. Then we computed the learning of the more and less initially knowledgeable children (Table 2).

**Number line linearity.** The 30 children in the linear board game condition were divided into 15 for whom the best fitting linear function accounted for 7% or more of the variance in pretest number line estimates (M = 50%) and 15 for whom the best fitting linear function accounted for 6% or less of the variance (M = 2%). The linearity of individual children’s number line estimates varied with pretest performance, F(1, 28) = 20.57, p < .001, \( \eta^2_p = .42 \) and session, \( F(1, 28) = 6.88, p < .05, \eta^2_p = .20 \). Linearity increased from pretest to posttest for those who scored below the median on the pretest, \( \tau(15) = 2.28, p < .05, d = .82 \), but not for those who scored above the median.

**Number line slope.** The median split on pretest performance resulted in a group of 15 children with above-median number line estimation slopes (M = .01, SD = .07, range = −.14 to .08) and a group of 15 children with below-median number line estimation slopes (M = .64, SD = .40, range = .14 to 1.27). Among children who played the linear board game, slope varied with pretest performance, \( F(1, 28) = 34.77, p < .001, \eta^2_p = .55 \) and session, \( F(1, 28) = 8.02, p < .01, \eta^2_p = .22 \). Slopes tended to increase for those whose pretest slope was above the median, \( \tau(14) = 2.10, p = .05, d = .39 \) and for those whose pretest slope was below the median, \( \tau(14) = 1.97, p = .07, d = .30 \).

**Numerical identification.** Children were divided into a group of 15 with fewer correct numerical identification answers on the pretest (8 or fewer, \( M = 5.3 \)), and a group of 15 with more correct numerical identification answers (9 or more correct identifications, \( M = 9.6 \)). Number of correct numerical identifications varied with pretest performance, \( F(1, 28) = 33.54, p < .001, \eta^2_p = .55 \), session, \( F(1, 28) = 11.63, p < .01, \eta^2_p = .29 \), and the pretest performance by session interaction, \( F(1, 28) = 20.68, p < .001, \eta^2_p = .43 \). Children whose pretest performance was below the median improved, \( \tau(14) = 4.37, p < .01, d = .59 \), but there was no change among the children whose pretest performance was above the median. The high pretest performance of the above-median group made ceiling effects a serious problem for this analysis.

**Numerical magnitude comparison.** Children were divided into a group of 15 with 78% or fewer accurate magnitude comparisons on the pretest (M = 64%) and a group of 15 with more than 78% correct

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**Table 1**

Correlations across tasks on pretest and posttest: All children.

<table>
<thead>
<tr>
<th>Pretest</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Number linearity</td>
<td>.89***</td>
<td>.44***</td>
<td>.39***</td>
<td>−.11</td>
<td></td>
<td>.84***</td>
<td>.82***</td>
<td>.41***</td>
<td>.39***</td>
<td>−.17</td>
</tr>
<tr>
<td>2. Number line slope</td>
<td>.47***</td>
<td>.37***</td>
<td>−.12</td>
<td></td>
<td>.79***</td>
<td>.85***</td>
<td>.45***</td>
<td>.40***</td>
<td>−.27*</td>
<td></td>
</tr>
<tr>
<td>3. Magnitude comparison</td>
<td>.48***</td>
<td>−.05</td>
<td></td>
<td></td>
<td>.49***</td>
<td>.53***</td>
<td>.83***</td>
<td>.42***</td>
<td>−.28*</td>
<td></td>
</tr>
<tr>
<td>4. Numerical identification</td>
<td>−.06</td>
<td>−.08</td>
<td>−.01</td>
<td>−.08</td>
<td></td>
<td>.89***</td>
<td>.46***</td>
<td>.46***</td>
<td>−.18</td>
<td></td>
</tr>
<tr>
<td>5. Absolute error addition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.46***</td>
<td>.39***</td>
<td>.39***</td>
<td>−.35**</td>
<td></td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01, *** p < .001.
Comparisons (M = 92%). Number of correct comparisons varied with group, $F(1, 28) = 51.99, p < .001, \eta^2_g = .65$. The two groups differed on both the pretest, 64% versus 92% correct; $t(28) = 7.83, p < .001, d = 2.86$, and the posttest, 65% versus 94% correct; $t(28) = 5.46, p < .001, d = 2.00$.

Counting. No analysis was possible, because 100% of children with pretest scores above the median counted perfectly.

Arithmetic. A median split on addition pretest performance led to identification of a group of 14 children with absolute error of 1.5 or more (M = 2.82) and a group of 16 children with absolute error of less than 1.5 (M = 1.31). Absolute error varied with group, $F(1, 28) = 9.24, p < .01, \eta^2_g = .25$, session, $F(1, 28) = 7.66, p < .05, \eta^2_g = .22$, and the group by session interaction, $F(1, 28) = 4.39, p < .05, \eta^2_g = .14$. Learning was greater among children whose pretest performance was worse. Accuracy increased (absolute error decreased) from pretest to posttest for children with below median accuracy on the pretest, $t(13) = 3.39, p < .01, d = 1.19$, but not for those whose pretest accuracy was above the median.

Discussion

Playing the linear numerical board game improved the numerical knowledge of 3- and 4-year-olds from middle-income backgrounds. The improvements extended to children's number line estimation (both linearity and slope), numeral identification, and ability to learn answers to novel addition problems. The gains from playing the linear board game were consistently greater than those produced by engaging in other numerical activities.

Playing the circular number board game improved children's numeral identification and ability to learn answers to novel arithmetic problems. Both gains were larger than those produced by engaging in the control numerical activities. This pattern of learning was similar for both the younger and older middle-income preschool children, even though the older preschool children demonstrated greater knowledge than the younger preschool children on the numerical estimation, magnitude comparison, and numeral identification tasks. Except for the improvement on the arithmetic task, which was not present for the circular board game condition in the earlier study, these results replicated those from Siegler and Ramani (2009).

The results suggest that the linear visual cue is helpful for preschoolers to learn about numerical magnitudes but that it is less important for tasks that do not directly measure knowledge of numerical magnitudes. In both the present study and in Siegler and Ramani (2009), children who played the linear board game improved on one or both measures that directly assess numerical magnitude representations (number line estimation and magnitude comparison), and in both studies, children who played the otherwise identical circular board game did not benefit on these measures. These studies, along with other recent research, demonstrate the usefulness of using linear board games to promote a wide range of types of numerical knowledge for preschoolers from a range of ages and backgrounds (Ramani & Siegler, 2008; Whyte & Bull, 2008).

Children who began with less knowledge tended to learn more from playing the linear board game than did children with greater initial knowledge. This reverse Matthew Effect was present on the number line estimation, numeral identification, and arithmetic tasks. For numeral identification the children with greater initial knowledge were close to ceiling, which limited their ability to show improvement. However, there was still an opportunity for the children with greater initial knowledge to show gains on the number line estimation and arithmetic tasks, which suggests that the catching-up findings are not due to ceiling effects alone on these tasks.

Other alternative interpretations of the greater learning of children with below average pretest performance on the three tasks involve unreliability of measurement and regression to the mean. If measures of pretest knowledge were unreliable, children in all groups who scored below the mean on the pretest would be expected to show greater pretest–posttest improvement than children whose pretest scores were above the mean, because both groups would tend to regress toward the mean (Barnett, van der Pols, & Dobson, 2005). However, as shown in Table 1, children in the numerical activities control condition did not show this pattern; there were no decrements in performance among children who initially scored above the mean and no increments among children who initially scored below the mean. Moreover, pretest–posttest correlations were very high in all conditions for all tasks except addition, thus indicating that these measures were in fact highly reliable. Thus, the observed changes in performance seemed to reflect initially less knowledgeable children learning more from playing the linear board game.

Experiment 2

The main goal of Experiment 2 was to compare the learning produced by the linear board game among the middle- to upper-middle-income sample of Experiment 1 to the learning of the low-income sample that participated in Siegler and Ramani (2009). The two experiments were designed with this comparison in mind; they employed identical experimental conditions, included identical numbers of children in each experimental condition, were performed by the same experimenters, and were conducted in successive months of the same year.

Because children of the same ages from low- and middle-income backgrounds differ in content knowledge, the design of the study required a choice between equating the samples on age or on content knowledge. We decided to equate initial numerical knowledge and allow age to vary. The reason was that previous studies that have systematically varied both age and initial knowledge have shown that knowledge exerts a greater influence on learning. For example, 10-year-old children who are more knowledgeable about chess are able to learn and remember new information on the topic more effectively than adults who are less knowledgeable (Chi, 1978; Schneider, Gruber, Gold, & Opwis, 1993). Similar advantages have been shown for younger third grade children who are more knowledgeable about soccer than older children who are less knowledgeable about it, and also more knowledgeable than age peers who have higher IQs (Schneider, Körkel & Weinert, 1989). Once knowledge is controlled,
age usually has no demonstrable effect on learning about chess or soccer (Chechile & Richman, 1982; Crowley & Siegler, 1999; Ghatala, 1984; Körkel & Schneider, 1991; Schneider & Bjorklund, 1998; Schneider et al., 1993).

To test the applicability of these findings regarding the relations to learning of knowledge and age to the current content domain and populations, we performed separate hierarchical regression analyses on the data from Experiment 1 and from Siegler and Ramani (2009). For each task, we first entered each child’s pretest performance as a predictor of the child’s posttest performance; then we tested whether the child’s age (in months) accounted for additional variance in posttest performance. The analysis for the data from Siegler and Ramani (2009) indicated that age did not add significant variance to that accounted for by pretest knowledge, regardless of whether the measure was number line linearity, number line slope, correct magnitude comparisons, correct numeral identifications, number of counts before the first error, or absolute error of addition answers. The data from Experiment 1 revealed an effect for age on only one of the six measures, arithmetic absolute error, on which it added 7% to the variance accounted for by pretest performance. In both experiments, children’s ages covered a substantial range (3.5–4.8 years and 4.0–5.5 years) relative to the mean age of the participants (4.0 and 4.8 years), thus indicating that the lack of an independent contribution of age was unlikely to be due to a restricted age range. Thus, it seemed reasonable to compare the learning of children from different economic backgrounds who were comparable in knowledge but different in age.

What patterns of learning from board games might be expected for children from middle-income and low-income backgrounds with equivalent initial knowledge? One possibility was that children from middle-income and low-income backgrounds derived similar benefits from playing the linear board game. Literature on the relation between knowledge and learning reviewed earlier indicates that prior knowledge is the main determinant of learning. This implies that in the present context, children from low- and middle-income backgrounds with comparable prior knowledge should show equal learning.

A second possibility was that children from middle-income backgrounds might have benefited more than children from low-income backgrounds from playing the linear board game. We labeled this idea the positive transfer hypothesis. It began with the assumption that prior experience playing board games and other experiences more common among children from middle-income families could improve subsequent learning from such games, because the prior experience with board games and other activities such as card games reduces the cognitive demands of routine aspects of the games, such as turn taking, moving one’s token a square at a time, and maintaining emotional equilibrium after losing a game to an opponent. Reductions in the demands of these routine aspects of the game would increase the cognitive resources available for more demanding aspects, such as learning about numerical magnitudes. The same prediction could be derived from a different logic; children from middle-income backgrounds might be higher in some third variable, such as IQ, that is related to learning and that might have allowed them to learn more than the children from low-income backgrounds.

A third possibility was that children from low-income backgrounds might have learned more from playing the numerical board games. We labeled this idea the redundant experience hypothesis. Its basic assumption was that children from middle-income families would have had more experience with board games prior to the experimental sessions. However, this greater prior board game experience could result in children from middle-income backgrounds learning less rather than more from new board game experience. This would occur if children from middle-income backgrounds had already gained more of the benefits that could be obtained from board game experience. Different types of experiences may have distinct (though overlapping) potential contributions to make to any given type of knowledge. To the extent that new experience duplicates prior experience, the potential contribution of the new experience might be reduced for the middle-income children. The new experience may also contribute to greater learning for the lower-income children who have not had as much prior opportunity to play board games. Providing children with such materials that can contribute to learning can produce larger gains in achievement for those who typically have less access to them (Kim, 2006). Thus, if the children from middle-income backgrounds in the present study had already derived substantial benefits from playing board games, and children from low-income backgrounds had not derived as much of that benefit, then the children from low-income backgrounds would be expected to have learned more from the board game experiences in the experiment.

The second goal of Experiment 2 was to compare children’s experiences with games outside of school. Consistent with the view that playing board games was useful for learning about numbers, Ramani and Siegler (2008) found that children from middle-income families had more experience playing board games at their homes and at other people’s homes than age peers from low-income backgrounds. To compare the board game experience of the younger children from middle-income backgrounds in Experiment 1 to that of the older children from low-income backgrounds in Siegler and Ramani (2009), we obtained self-report data from the children regarding their experiences outside of school playing board games, card games, computer games, and video games. This information was essential for evaluating the positive transfer and redundant experience hypotheses, because both depended on the assumption that children from middle-income families would have had greater experience with board games.

**Method**

**Knowledge matching procedure**

Our first goal was to insure that children in the low-income and middle-income samples possessed equivalent initial knowledge. Pilot testing, along with the results of Starkey et al. (2004), indicated that an 8-month difference between children from the different economic backgrounds would yield this outcome. However, a MANOVA on the pretest performance of the two groups of children indicated that the middle-income sample began the study with greater numerical knowledge, though younger by eight months, $F(4, 171) = 4.69, p < .01, \eta^2_p = .10$. Separate ANOVAs for each measure indicated that the children from middle-income backgrounds generated number line estimates that were more linear (mean $R^2_{lin} = .27$ versus $.15$, $F(1, 175) = 7.99, p < .01, \eta^2_p = .04$), and that had higher slopes, (mean slope = .31 versus .11, $F(1, 175) = 11.23, p < .01, \eta^2_p = .06$); more often correctly answered magnitude comparison problems (79% versus 69% correct, $F(1, 175) = 13.75, p < .001, \eta^2_p = .07$; and identified more numerals correctly (means of 7.5 versus 6.4 correct, $F(1, 175) = 6.48, p < .05, \eta^2_p = .03$).

Therefore, to identify the largest possible subset of each sample with equal initial knowledge, we created a composite measure of pretest performance and then matched individual children from the two samples. We first computed $z$-scores for all 176 children on each of five measures of pretest performance — linearity and slope of number line estimates, number of correct magnitude comparisons, number of correct numeral identifications, and mean absolute error on the addition problems. (Counting scores were not included, because the large majority of children in both samples were at ceiling.) Mean $z$-scores of children from middle-income families ranged from $-1.11$ to $1.58$ ($M = .13, SD = .57$); mean $z$-scores for children from low-income families ranged from $-1.31$ to $1.13$ ($M = -.13, SD = .55$). To create comparable samples, the mean $z$-score of a child from a middle-income family was matched with that of a child from a low-income family whose average $z$-score was within .05 of
that of the child from the middle-income family. When more than one child provided a suitable match, the child was chosen who would best equate the number of participants within each experimental condition. Age, gender, and race were not taken into consideration when making the matches. If a suitable match could not be found for a child, then the child was not included in the subsequent analyses.

This matching procedure allowed identification of 66 of the 88 children (75%) in each original sample with closely comparable initial knowledge. These children's pretest performance did not differ on any of the tasks. Among the 66 children in each sample, exactly 22 participated in each of the three experimental conditions. Alternative sub-samples were created by matching children's pretest scores within .03 and within .10 average z-scores; these procedures yielded similar patterns of results to the ones described subsequently and therefore are not reported.

Note that this approach is not subject to the criticism of systematic non-matching, which refers to the possibility that when matching the children on initial knowledge we are creating a nonrepresentative sample for the study. As a result, this can greatly limit the generalizability of the results (Breau & Arnold, 2007; Meekel, 1970). However, the generalizations being drawn from the study are to preschoolers from low-income and middle-income backgrounds with comparable initial numerical knowledge, which are the groups included in the analysis, rather than to any particular age group of preschoolers from low- and middle-income backgrounds.

Participants
The 66 preschool participants in the low-income sample were recruited from seven Head Start classrooms and two child care centers in the same neighborhoods. These children, 59% of whom were female, ranged in age from 4 years 0 months to 5 years 5 months (M = 4 years 7 months, SD = .45); 36% were African American, 58% Caucasian, and 6% Other (Asian, Hispanic, Biracial, or Unknown). The families from the Head Start classrooms met the income requirements for Head Start established by the Federal government for 2007 (e.g. for a family of three, annual income below $17,170). Almost all (96%) of the families whose children attended the child care centers received government subsidies for childcare expenses. The mean age of preschoolers in the linear board condition was 4 years, 6 months (SD = .40); 68% of children were female, 50% African American, 41% Caucasian, 9% Other. The mean age of preschoolers in the circular board game condition was 4 years, 7 months (SD = .48); 55% of children were female, 23% African American, 69% Caucasian, 8% Other. The mean age of preschoolers in the numerical control condition was 4 years, 6 months (SD = .49); 55% of children were female, 36% African American, 64% Caucasian.

The 66 preschoolers in the middle-income sample ranged in age from 3 years 5 months to 4 years 8 months (M = 4.0 years, SD = .35; 62% were female, 77% Caucasian, 23% Other). Children in the linear board condition had a mean age of 4.0 years (SD = .31); 59% were female, 73% Caucasian, 27% Other. Children in the circular board game condition had a mean age of 4.0 years (SD = .35); 64% were female, 68% Caucasian, 32% Other. Peers in the numerical activities control condition also had a mean age of 4.0 years (SD = .39); 64% were female, 91% Caucasian, 9% Other. The same experimenters tested both the low- and middle-income samples.

Materials and procedure
The experimental conditions, materials, and numerical knowledge measures were the same as described in Experiment 1. Also similar to Experiment 1, each child from the Head Start sample in the numerical activities control condition was paired with a child of the same age (within 2 months) in a board game condition, and the length of each session was matched to equate the amounts of time spent playing between the board game and numerical control conditions. T-tests between the middle- and low-income children within each condition indicated that children from the two samples played each of the games for an equal amount of time.

Immediately after the arithmetic posttest in Session 5, children were presented questions about their game-playing experience outside of preschool. The experimenter asked whether the children ever played board games, card games, video games, and computer games at their homes. The experimenter also asked whether the children played each of the types of games at other family members’ or friends’ homes. If children responded “yes” to any of those questions, they were asked whether they played that type of game “all the time, sometimes, or hardly ever” and also were asked to name each board game, card game, video game and computer game they had played outside of preschool. Although these data on game playing experience were collected at the same time as other data from Siegler and Ramani (2009), the data were not included in the earlier article. Due to experimenter error, data on game experience outside of school were not collected from one child from a low-income family.

Results

Multivariate effects
A MANOVA indicated no differences in pretest performance between the middle-income and low-income samples. Thus, the matching procedure allowed identification of groups of preschoolers from low- and middle-income backgrounds with comparable initial knowledge.

We next conducted a 2 (SES: Low- or middle-income) × 3 (condition: Linear board game, circular board game, or numerical activities control) × 2 (session: Pretest or posttest) repeated measures MANOVA on the five measures described in Experiment 1. Effects emerged for the condition by session interaction, F(10, 240) = 4.22, p < .001, ƞ_p^2 = .15, and tended to vary with session, F(5, 120) = 1.94, p = .09, ƞ_p^2 = .08. Univariate analyses were therefore conducted for each measure to examine the consistency of results across tasks and to better understand the interaction. Race (African American; Caucasian and Other) and gender were included as covariates, because they were not controlled in the matching procedure and the effects of these variables are unknown. No significant effects were found for gender, and race was only significant in one of the ANOVAs, therefore gender and race were not analyzed further. As can be seen in Fig. 2, the most striking finding was that although preschoolers from both low-income and middle-income background benefited from playing the linear board game, the children from low-income backgrounds tended to benefit more.

Number line estimation
Linearity. Individual children’s linearity of number line estimates varied with session, F(1, 124) = 3.77, p = .05, ƞ_p^2 = .03, and with the condition by session interaction, F(2, 124) = 5.61, p < .01, ƞ_p^2 = .08. Children who played the linear board game showed greater pretest–posttest improvement than the other two conditions for both low-income and middle-income samples. For the children from low-income families who played the linear board game, linearity increased from 16% on the pretest to 38% on the posttest, t(21) = 3.57, p < .01, d = .86. Linearity also increased for children from middle-income backgrounds, although the changes were not as large: 17% on the pretest versus 29% on the posttest, t(21) = 2.24, p < .05, d = .36. These data indicated that playing the linear game had a large effect on the knowledge of children from low-income backgrounds (d = .86) and a medium size effect on children from middle-income ones (d = .36) (by Cohen’s, 1988, criteria). In contrast to children who played the linear board game, there were no significant changes among children who played the circular board games for the children from low-income backgrounds (mean R^2_lin = .15 and .22) or from middle-income backgrounds (mean R^2_lin = .17 and .23). Similarly, among the children in the numerical activities control condition, linearity of estimates did not increase from pretest to posttest.
either for the children from less affluent backgrounds (mean $R^2_{\text{lin}} = .18$ and .22) or more affluent ones (mean $R^2_{\text{lin}} = .18$ and .16).

Slope. Analyses of the slopes of individual children’s number line estimates indicated effects for session, $F(1, 124) = 7.94, p < .01, \eta^2_p = .06$, and the condition by session interaction, $F(2, 124) = 9.79, p < .001, \eta^2_p = .14$. Among children who played the linear board game, the mean slope of number line estimates increased substantially from pretest to posttest for the children from low-income backgrounds, mean slope = .12 versus .56, $t(21) = 4.16, p < .01, d = 1.32$. It also increased somewhat for children from wealthier backgrounds, mean slope = .20 versus .40, $t(21) = 2.97, p < .01, d = .44$. These data indicated considerably larger effects for the children from poorer backgrounds than for the children from wealthier ones ($d’s = 1.32$ versus .44).

For children who played the circular board games, pretest–posttest changes in slope were not significant among children from low-income families, mean slope = .12 and .29, or from middle-income families, mean slope = .20 and .27. Among children in the numerical control condition, there were no pretest–posttest changes among children from either impoverished backgrounds (mean pretest and posttest slopes = .15), or wealthier ones (slope = .16 and .11).

**Numerical magnitude comparison**

Accuracy on the numerical magnitude comparison task varied with the condition by session interaction, $F(2, 124) = 3.53, p < .05, \eta^2_p = .05$. Among children in the low-income sample who played the linear board game, accuracy increased from pretest to posttest, 70% to 78%, $t(21) = 3.01, p < .01, d = .53$. Among children in the middle-income sample, gains were small and not significant (74% on the pretest, 77% on the posttest).

There were no pretest–posttest changes in magnitude comparison accuracy among children who played the circular board game in either the low-income sample (73% and 76% correct) or in the middle-income sample (75% and 77% correct). Similarly, among children who engaged in the numerical control activities, there was no change over sessions in magnitude comparison accuracy for the children from poor backgrounds (72% and 67% correct) or for peers from wealthier backgrounds (74% and 76% correct).

**Counting**

The large majority of children were already at ceiling on the pretest in both the low-income sample (92%) and in the middle-income sample (92%), thus precluding meaningful statistical comparisons.

**Numerical identification**

Number of correct numeral identifications varied with the condition by session interaction, $F(2, 124) = 4.41, p < .05, \eta^2_p = .07$. Among children who played the linear board game, numeral identification improved from pretest to posttest for both preschoolers from low-income families, 6.7 versus 7.9 correct, $t(21) = 3.69, p < .01, d = .51$, and middle-income families, 7.0 versus 7.9 correct, $t(21) = 2.51, p < .05, d = .29$. Similarly, among children who played the circular board games, numeral identification improved from pretest to posttest for children from both low-income backgrounds, 7.5 to 8.1 correct, $t(21) = 2.16, p < .05, d = .18$, and middle-income backgrounds, 7.0 to 7.8 correct, $t(21) = 2.25, p < .05, d = .19$. In contrast, among children in the numerical control condition, numeral identifications did not improve for either the less affluent group (6.9 and 7.2 correct) or the more affluent one (7.4 and 7.4 correct).

**Arithmetic**

Because the problem selection criteria guaranteed 0% correct on the pretest for trained problems, statistical comparisons involved comparisons of posttest performance. Among preschoolers from low-income backgrounds, having played the linear board game improved learning of the arithmetic problems. They answered more addition problems correctly after training than did children who earlier had played the circular board game (45% versus 25% correct) or children who earlier had engaged in the numerical control activities (45% versus 27% correct). $X^2(4, N = 65) = 9.47, p < .05$. The number of correct answers of preschoolers from middle-income backgrounds did not differ significantly among the three groups, though directional effects were present (37% and 48% correct for those in the linear board and circular board conditions, 28% for those in the numerical control activities condition).

Among children who played the linear board game, absolute error on the arithmetic problems decreased from pretest to posttest both for
children from families with low incomes, mean error = 2.5 versus 1.2, \( t(21) = 2.63, p < .05, d = .83 \), and for children from families with higher incomes, mean error = 2.2 versus 1.1, \( t(21) = 3.66, p < .01, d = 1.12 \). Among children who had played the circular board game, there was also a decrease in absolute error among children from wealthier families, mean error = 1.9 versus 1.1, \( t(20) = 2.28, p < .05, d = .69 \), but no significant changes among children from low-income families, mean error = 2.1 versus 1.9. Among children who had engaged in the numerical control activities, there was no change in absolute error among preschoolers from either background.

**Game playing experience outside of school**

We also examined whether there were differences between the percentage of children from lower- and higher-income backgrounds who had experience at their homes, at other people's homes, or both with board games, card games, computer games, and video games. Despite the children from middle-income backgrounds being younger, a higher percentage of them reported experience outside of school with board games (68% versus 52%, \( N = 131, p < .05, \text{Fisher Exact Test} \)), card games (67% versus 43%, \( N = 131, p < .01, \text{Fisher Exact Test} \)), and computer games (70% versus 45%, \( N = 131, p < .01, \text{Fisher Exact Test} \)). A difference in the opposite direction was found for videogames; 63% of children from low-income backgrounds reported playing videogames at home, but only 36% of the children from middle-income backgrounds did (\( N = 131, p < .05, \text{Fisher Exact Test} \)).

We also compared the number of board games, card games, computer games, and video games that children from the higher- and lower-income backgrounds named as ones that they had played. Children from middle-income backgrounds named more board games (means of 1.47 versus 1.03, \( t(129) = 1.98, p < .05, d = .35 \)), card games (1.05 versus .71, \( t(129) = 2.05, p < .05, d = .36 \)) and computer games (1.30 versus .85, \( t(129) = 2.08, p < .05, d = .35 \)). In contrast, children from low-income backgrounds named a greater number of videogames as ones they had played at their own or other people's homes (means of 1.31 versus .61, \( t(129) = 3.38, p < .01, d = .59 \)).

**Discussion**

The goal of the experiment was to compare the improvements from playing the linear board game of low- and middle-income samples with equal initial numerical knowledge. The logic of the positive transfer hypothesis suggested that children from middle-income backgrounds would learn more, the logic of the redundant experience hypothesis suggested that children from low-income backgrounds would learn more, and the logic that knowledge determines learning suggested that children in both groups would learn the same amount.

The results clearly argued against the positive transfer hypothesis. Children from middle-income backgrounds had more board game experience, but they did not learn more than children from low-income backgrounds from playing the present board game.

Although some evidence suggested that children from low-income and middle-income backgrounds learned an equal amount, most of the evidence suggested that children from low-income backgrounds learned more. The number of correct magnitude comparison and arithmetic answers of children from low-income backgrounds showed significant gains, whereas number correct on the same tasks of children from middle-income backgrounds did not. On the number line and numeral identification tasks, both groups showed significant gains, but the gains of children from low-income families in both linearity and slope of estimates were larger: \( d's \) of .36 versus .32 for number line linearity, 1.32 versus .44 for number line slope, and .51 versus .29 for number line identifications. Not all of the data followed this pattern — children from middle-income backgrounds improved more on the measure of arithmetic absolute error, \( d's = 1.12 \) versus .83.

It might be tempting to explain these surprising results on the basis that the children from low-income backgrounds were older, and therefore that they might have been better learners. However, a number of types of evidence argued against this interpretation. As noted in the introduction, in a variety of domains, older and younger children with similar knowledge have been found to show similar learning (Chechine & Richman, 1982; Crowley & Siegler, 1999; Ghatala, 1984; Schneider & Bjorklund, 1998). Complementarily, when both knowledge and age vary, only knowledge has been found to explain significant independent variance (Chi, 1978; Schneider et al., 1989). Perhaps most convincing, in both data sets examined in the present study, age did not account for independent variance in posttest performance once knowledge was controlled. Thus, neither past nor present evidence supported the view that differences in age accounted for the differences in learning in the present low-income and middle-income samples.

**General discussion**

In this study, we examined the absolute and 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. Consistent with our first main hypothesis, playing a linear number board game improved the numerical knowledge of preschoolers from middle-income families. Consistent with our second main hypothesis, the children from low-income families learned at least as much, and on most measures more, than the preschoolers from middle-income families. Next, we discuss these findings and their implications.

**Benefits of playing number board games for children from middle-income backgrounds**

The results of Experiment 1 demonstrated that playing a linear board game improves the numerical knowledge of 3- and 4-year-olds from middle- and upper-middle-income backgrounds. The gains were evident for number line linearity and slope, numeral identification, and arithmetic learning. The findings closely replicated Siegler and Ramani's (2009) findings with 4- and 5-year-olds from low-income backgrounds. As with children from low-income backgrounds, children from middle-income backgrounds learned more from playing a linear board game than from playing a circular game. The one difference from the findings with children from low-income families was that the children from middle-income backgrounds who played the linear board game did not improve on magnitude comparison. This difference was not expected, especially because prior studies had shown that African American and European American preschoolers from low-income backgrounds and British children from working class backgrounds improved on this task (Ramani & Siegler, 2008; Whyte & Bull, 2008).

Children from middle-income backgrounds with less initial knowledge learned more from playing the linear board game than peers with greater initial knowledge. The greater improvement in numeral identification of children with below-average pretest performance was attributable to ceiling effects, but the other differences could not be explained in this way. The differences also were not attributable to unreliability of measurement; pretest–posttest correlations indicated exceptionally high stability of individual difference in performance. The tendency of the students with poorer initial performance to learn more also was not attributable to regression to the mean; differences between children with below-median and above-median initial performance stayed quite constant for children in the numerical control activities condition, where little change in mean performance occurred.
Relative benefits for children from low- and middle-income backgrounds

The second main goal of the study was to compare the improvements from playing the linear board game of low- and middle-income samples with equal initial numerical knowledge. Overall, the results seem to suggest that children from low-income backgrounds learned more than the middle-income children. These findings are the opposite of the usual “rich get richer” pattern, in which children who are from more affluent backgrounds or who are initially more knowledgeable learn more than their less affluent peers (Entwisle & Alexander, 1990; Jordan, Huttenlocher, & Levine, 1992; Starkey & Klein, 1992).

The data from the within-sample comparisons of children with above-median and below-median pretest knowledge who played the linear number board game were consistent with this “poor get richer” pattern. In the middle-income sample, performance improved significantly from pretest to posttest for children with below-average knowledge but not for peers with above-average knowledge on three of the four numerical knowledge tasks. Similarly, in Siegler and Ramani (2009), gains were larger for children with above-average knowledge on all of the tasks.

Given that the less knowledgeable middle-income in the present study, and the low-income children from Siegler and Ramani (2009) learned more, and given that previous investigators (e.g., Starkey et al., 2004) found as we did that preschoolers from low-income backgrounds tended to learn more from mathematics interventions, the “poor get richer” pattern seems worth trying to explain. Starkey et al. (2004) speculated that parts of their curriculum might have been aimed too low for some of the children in their study from middle-income backgrounds. It is also possible that parts of the present board game, such as information about the first few numbers, might be redundant with some children's initial knowledge, and ceiling effects were a problem for analyzing the learning of the initially more knowledgeable children on the numeral identification task. However, on the number line estimation, magnitude comparison, and arithmetic tasks, even the more knowledgeable children had a great deal left to learn, and ceiling effects were not an issue. In addition, any redundancies of the board game with initial numerical knowledge seemed likely to affect both low-income and middle-income samples.

A different type of redundancy, redundancies in the experiences that led to the children's knowledge, might provide a better explanation. Although the children from low- and middle-income backgrounds in the present study had equivalent numerical knowledge on the pretest, the knowledge may have come from different types of experiences. The data indicated that the children from middle-income backgrounds had more experience with board games, card games, and computer games, despite being younger. This suggests that the children from low-income backgrounds must have obtained their initial knowledge from having more of some other types of experiences. This raised the question of what those experiences might be.

Studies of children's numerical environments indicate that the most common numerical activity in both homes and preschools is counting (Plewis, Mooney, & Creeser, 1990; Tudge & Doucet, 2004). The children from low-income backgrounds in the present study may well have had greater experience with counting at home and at preschool, because they had more time to have had such numerical experiences. They also would have had more time to watch educational television programs such as Sesame Street and Dora the Explorer, which also emphasize counting. In addition to being a useful skill in itself and for solving arithmetic problems, counting experience also seems likely to have provided information about magnitudes. In particular, counting rows of objects provides children with opportunities to learn that higher numbers accompany longer rows, that counting to higher numbers takes more time and more physical movements, and that higher numbers accompany objects farther down the row from the origin. Consistent with this view that counting objects can improve understanding of numerical magnitudes, Chinese kindergartners, who have more experience with counting than their U. S. peers but are equally unfamiliar with number line estimation, nonetheless estimate numerical magnitudes far more accurately (Siegler & Mu, 2008).

Thus, greater counting experience among children from low-income backgrounds might compensate for the greater board game experience of children from middle-income backgrounds. This suggests that the children from low-income backgrounds in the present study might have learned more from board game experience because that experience was more novel to them, and provided a more novel route for learning about numbers. Consistent with this analysis, learning from the board game is greater in the first two sessions, when the game is relatively novel, than in subsequent sessions (Siegler & Thompson, in preparation).

The role of informal activities in early numerical development

The present findings add to a growing body of research that suggests that engaging in informal numerical activities can play a critical role in children's early numerical development. Preschoolers from both lower and higher income backgrounds are interested in math-related activities, and they engage in similar amounts of math-related play at preschool when similar resources are available (Clements & Sarama, 2007; Ginsburg & Amit, 2008; Ginsburg, Pappas, & Seo, 2001; Seo & Ginsburg, 2004). However, there is still a large discrepancy between the numerical knowledge of young children from more and less affluent backgrounds (Case & Okamoto, 1996; Denton & West, 2002; Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006). The present findings suggest that differences in the types of informal activities in which children engage in at home is a possible contributor to differences in numerical knowledge. A higher percentage of preschoolers from middle-income than low-income backgrounds report playing board games at home, even when the preschoolers from middle-income backgrounds are considerably younger. Although many informal activities, such as board games, are designed for encouraging interactions between parents, siblings, and peers, they can provide children with important numerical information. The learning from these informal activities is often indirect because the instruction is integrated into the everyday activity.

Direct instruction, such as strategies for solving arithmetic problems and encouraging children to memorize the answers to the problems also appears to be influential. Amount of direct parental instruction about numbers is positively related to young children's numerical knowledge (Blevins-Knabe & Musun-Miller, 1996; Huntsinger et al., 2000; LeFevre, Clarke, & Stringer, 2002). Engaging in both informal activities and direct instruction at home can have long-term benefits for children's mathematical development (Melhuish et al., 2008). Moreover, randomized controlled trials have demonstrated that preschool curricula that include both informal activities and direct instruction produce large improvements in the mathematical knowledge of low-income preschoolers and kindergartners in areas such as number, geometry, and measurement. These curricula include Number Worlds (Griffin, 2007), Building Blocks (Clements & Sarama, 2007), and Big Math for Little Kids (Ginsburg, Greens, & Balfanz, 2003).

A large body of evidence, including the present data, provides good reason to advocate that parents and teachers more frequently engage preschoolers in mathematical activities. This evidence includes the finding that in mathematics, children who start behind stay behind, and also the finding that young children's number skills can be improved quickly and substantially through a variety of informal and formal numerical activities. The present study suggests that linear numerical board games are one potential tool for increasing young children's knowledge of small numbers in homes and schools. Such games are easy to create, easy for teachers and parents to utilize, require minimal time to play, and are extremely inexpensive. Thus, it seems critical to play such board games, engage in other informal
math activities, and make available mathematics curricula of proven effectiveness to a wider range of preschoolers, especially preschoolers from low-income backgrounds.

Acknowledgments

We would like to thank the Department of Education, which supported this research through its Instructional and Educational Science Program, Grant R200H000012, and R305H050035. We also would like to thank the administrators, parents, and children in the Beth Shalom Child Care Center, Carnegie Mellon Children’s Center, Carriage House Children’s Center, Children’s Center of Pittsburgh, Point Park Children’s School, and University of Pittsburgh Child Development Center for their participation and cooperation in the research. Thanks also to Mary Wolfsion and Rachel Beberman for their help in collecting and coding the data.

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