Published in final edited form as:

J Learn Disabil. 2013 March ; 46(2): 166–181. doi:10.1177/0022219411410233.

A Number Sense Intervention for Low-Income Kindergartners at Risk for Mathematics Difficulties

Nancy I. Dyson, Nancy C. Jordan, and Joseph Glutting

University of Delaware

Abstract

Early number sense is a strong predictor of later success in school mathematics. A disproportionate number of children from low-income families come to first grade with weak number competencies, leaving them at-risk for a cycle of failure. The present study examined the effects of an 8-week number sense intervention to develop number competencies of low-income kindergartners ($n = 121$). The intervention purposefully targeted whole number concepts related to counting, comparing, and manipulating sets. Children were randomly assigned either to a number sense intervention or a business as usual contrast group. The intervention was carried out in small group, 30-minute sessions, 3 days per week for a total of 24 sessions. Controlling for number sense at pretest, the intervention group made meaningful gains relative to the control group at immediate as well as delayed posttest on a measure of early numeracy. Intervention children also performed better than controls on a standardized test of mathematics calculation at immediate posttest.

Keywords

at-risk; mathematics; number sense; low income; intervention

The mathematics achievement gap between low- and middle-income children in the U.S. is wide and persistent. Although low-income children have made achievement gains in recent years, so have their middle-income peers, leaving the gap virtually unchanged at the end of eighth grade (National Center for Education Statistics, 2009). Even more disturbing, achievement disparities between these groups have been documented before children enter school (Duncan, et al., 2007; Lee & Burkham, 2002; National Research Council, 2009). A disproportionate number of children from low-income families come to kindergarten without the skills necessary for success in formal mathematics and are over-represented in the population of students with diagnosed mathematics difficulties and disabilities (Jordan & Levine, 2009). Poor mathematics achievement can have far reaching consequences. Low-income students are likely to be less prepared than middle-income students in the important STEM disciplines for which mathematics is a prerequisite. Mathematics proficiency has long been seen as a gateway to highly sought after professions in science, technology, engineering, and mathematics (National Mathematics Advisory Panel, 2008).

Until recently, early intervention for children in mathematics has been overlooked, especially with the emphasis on literacy in kindergarten and early elementary school (Gersten Jordan, & Flojo, 2005). However, in its recent report, *Mathematics Learning in Early Childhood: Paths toward Excellence and Equity* (National Research Council, 2009),

the Committee on Early Childhood Mathematics identified two core areas of early mathematics that must be addressed in preschool and kindergarten: number and geometry/measurement. The present study focuses on the core area of number, because, as underscored by the Committee, number competence is of primary importance for success to school mathematics.

Most children come to school with number competencies that are developed through their informal experiences (Ginsburg, Lee, & Boyd, 2008). Many parents and caregivers engage their children in “number talk” (Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006) and encourage them to count and compare quantities in daily life. Researchers have defined interrelated number competencies that are highly associated with later success in school mathematics. These competencies, also referred to as *number sense*, involve understanding of whole numbers, number operations, and number relations (Malofeeva, Day, Saco, Young, & Ciancio, 2004). In particular, they include recognition that numbers represent quantities and have magnitudes, that counting is guided by principles related to one-to-one correspondence, fixed order, and cardinality, and that sets can be transformed through addition and subtraction (Gelman & Gallistel 1978; Griffin, 2004).

All of these abilities involve symbolic representations of numbers, verbal or written, in contrast to more fundamental preverbal number knowledge that appears to develop without verbal input or instruction (Feigenson, Dehaene, & Spelke, 2004; Jordan & Levine, 2009). In order to navigate formal mathematics, children must be able to link their basic understanding of numbers to symbolic representations (Carpenter, Hiebert, & Moser, 1983; Gersten, Jordan, & Flojo, 2005; Hiebert, 1984). Deficits in these connections (e.g., being able to compare the magnitude of sets of objects but not being able to compare the magnitude of the numerals associated with these sets) are associated with mathematics learning disabilities (Rousselle & Noëlle, 2007).

Counting knowledge is of central importance to numerical development because it extends quantitative understanding beyond very small numbers, which initially are recognized as whole units (Baroody, 1987; Baroody, Lai, & Mix, 2006; Ginsburg, 1989). Before kindergarten, most children grasp that each object in a set is counted once and only once, that the count words are always used in the same sequence (i.e., 1, 2, 3, etc.), and that the last number in the count always denotes the number of objects in the set (Gelman & Gallistel, 1978). Children gradually learn that they can count objects presented in any configuration as long as they count each object only once.

Young children also learn to compare the magnitudes of numbers and symbols (Case & Griffin, 1990; Griffin, 2002; Griffin, 2004). For example, they can tell which of two piles of objects has more or less and eventually that the written number 4 is bigger than 3 or that 2 is smaller than 5 (Griffin, 2004). Linking number words to quantities helps children see relations between and among numbers on the number line (e.g., before/after, bigger/smaller) (Griffin & Case, 1997). A particularly important insight is the knowledge that the next number in the count sequence or on a number list is one more than the preceding number – for all numbers, no matter how large or how small. This insight allows children to use counting strategies adaptively for addition and subtraction (e.g., $n + 1$; $n - 1$). It also helps them internalize answers to combinations based on relations between numbers in the count sequence (Baroody, Eiland, & Thompson, 2009).

Kindergartners also are capable of learning base-10 concepts (Fuson, Grandau, & Sugiyama (2001). Such concepts help children understand numbers with two or more digits and lay a foundation for instruction in first grade. Fuson et al. highlight the need for purposeful instruction of number recognition, which is commonly taught by rote in kindergarten, built

on base-10 representations. For example, when children are shown that the written number 15 represents “fifteen,” they should also learn that this means one ten and five ones.

Competence with addition and subtraction operations is a hallmark of primary school mathematics. However, these abilities start to develop much earlier. Although preschoolers have limited success with verbal story problems (“Beth had 2 pennies. Jill gave her 1 more penny. How many pennies does Beth have now?”) and number combinations (“How much is 2 and 1?”), many can solve “nonverbal” calculations with object representations (e.g., The child is shown 2 objects that are then hidden with a cover. One more object is slid under the cover by the examiner, and the child must calculate to determine that 3 objects are now under the cover) (Levine, Jordan & Huttenlocher, 1992). Even children with limited counting facility can solve these kinds of problems with totals of 5 or less by visualizing sets when objects have been added or removed (Huttenlocher, Jordan, & Levine, 1993). Early performance on nonverbal calculation is associated with later addition and subtraction skill (Levine et al., 1992).

Another important understanding related to addition and subtraction is that numbers can be broken into smaller sets of numbers. For example, the number 5 can be broken into 1 and 4, or into 2 and 3. Fuson, Grandau, & Sugiyama (2001) refer to combinations as “partners” for particular totals. Thinking about different partners for the same sums and also relating them to subtraction encourages flexibility when solving problems.

Success in primary school mathematics requires children to connect understandings of object-based calculations to verbal story problems and number combinations. Low-income children typically perform far below their middle-income peers on story problems and number combinations (Jordan, Kaplan, Nabors, & Locuniak, 2006; Starkey, Klein, & Wakeley, 2004) but not on nonverbal problems (Jordan, Huttenlocher, & Levine, 1992). Observations of children’s performance show that low-income kindergartners do not make use of counting strategies to help them calculate with larger numbers (Jordan et al., 2006). Consequently, an important aspect of early intervention for high risk learners is to help them link their developing knowledge of addition and subtraction, as demonstrated on the nonverbal problems, to conventional verbal combinations through counting and mental representation.

Predictability of number sense

In recent longitudinal work, Jordan and colleagues (Jordan, Kaplan, Ramineni, & Locuniak 2009; Jordan, Glutting, & Ramineni, 2009; Jordan, Glutting, Ramani, & Watkins, 2010; Locuniak & Jordan, 2008) found that core number competencies in kindergarten (counting, number knowledge, and number operations) are highly predictive of mathematics computation and problem solving proficiency through at least third grade, even when controlling for reading, age, and general cognitive factors. They also found that the vast majority of children lacking in these competencies are from low-income populations (Jordan, Kaplan, Locuniak, & Ramineni 2007; Jordan, et al., 2006). Similar results have been reported with shorter-term studies (Clarke & Shinn, 2004; Lembke & Foegen, 2009; Methe, Hintze, & Floyd, 2008). Moreover, number competence in preschool predicts performance on similar measures in kindergarten (VanDerHeyden, Broussard, & Cooley, 2006). If, as suggested, early number competencies mediate success in school mathematics, it would be especially important to determine whether these competencies can be developed through targeted interventions to change learning outcomes (VanDerHeyden, 2010).

Intervention Research

Recent studies suggest that early number competencies are malleable, or in other words, they can be taught to most children. Some of the most compelling work has come from Siegler and colleagues, who have identified specific number activities that can improve numerical understanding in preschoolers from low-income families. They have demonstrated the positive effects of playing board games that involve linear number representations (i.e., board games with consecutively numbered, equal-size spaces) (Siegler, 2009). Such games also develop counting knowledge (e.g., one-to-one correspondence) and number identification skills. Using random assignment, Ramani and Siegler (2008) taught children from Head Start centers to play either a number-board game or a color board game that did not involve numbers. Children played the games for 20 minutes on four occasions over a two-week period. Children in the number board game condition made reliable gains in their ability to estimate numbers on a number line, relative to the children who played the color board game. The number board game also improved children's ability to compare which of two numbers is bigger, to identify written numbers by name, and to count from 1 to 10. Siegler (2009) suggests that because many low-income preschoolers have had little direct experiences with mathematics, number interventions provide an effective environment for prompting development.

Baroody, Eiland, and Thompson (2009) conducted an intervention study in which children between the ages of four and five were instructed for ten weeks, three times a week, in small groups using manipulatives and games that focus on what the researchers considered to be developmental prerequisites for mental arithmetic (basic number concepts, verbal counting, object counting, and numerical relations). In a second phase, children were trained one-on-one in mental arithmetic for another ten weeks. Children made significant gains in the Test of Early Mathematics Achievement- 3rd edition (TEMA-3). The absence of a non-intervention comparison group, though, makes it impossible to assess the true effectiveness of the intervention

Chard, Baker, Clarke, Junghohann, Davis, and Smolkowski (2008) developed a mathematics curriculum (Early Learning in Mathematics) that focused on number sense, among other areas of mathematics. The number activities used the number line for counting, numeral identification, quantity discrimination, and before and after activities. The impact of the curriculum was tested on a population of kindergartners, about half of whom came from low-income families. Children who received the curriculum in their classrooms tended to perform better than a comparison group on an early achievement measure (Stanford Early School Achievement Test), which was closely aligned with the curricula. Although the findings are suggestive, the curriculum integrated several areas of mathematics (i.e. number sense, geometry, and measurement), making it difficult to determine the impact of the number sense instruction in particular. More important, however, it is difficult to draw conclusions about causality because the study did not use random assignment for the experimental and comparison conditions and there were substantial differences between the groups in mathematics at baseline.

The present study

In the present study, we developed and tested a purposeful eight-week number sense intervention for kindergartners from low-income families. Kindergarten is an important time to provide educational interventions. If children leave kindergarten with weak number competencies, they enter first grade at a disadvantage and may never catch up to those who started with good number competencies (Jordan et al., 2009). Such a consequence is reported in the content area of reading. Juel (1988) reported that children who entered first

grade with little or no early literacy skills almost always became poor readers. However, the National Reading Panel (2000) reports that early intervention in these same early literacy skills can move an at-risk kindergartner onto an appropriate learning trajectory. It is reasonable to assume that the same would be true for early intervention in number sense.

The intervention was based on the premise that weaknesses in key number competencies underlie mathematics difficulties and that these competencies can be developed early through targeted instruction. It emphasized whole number concepts related to counting, comparing, and manipulating sets. To help children attend to number, we used consistent representations (primarily chips, black dots and fingers) and centered activities on a number list from one to ten. Previous work has shown that young children often focus on perceptual variables in tasks rather than on relevant numerical information in mathematics-related activities (Rousselle, Palmers, & Noël, 2004). Finger counting was an area of particular focus. Fingers are an accessible resource for representing numbers and counting, and low-income kindergartners use their fingers less often than middle-income children (Jordan, et al., 1992; Jordan, Kaplan, Ramineni, & Locuniak, 2008).

The study used a pretest, post test, and delayed post test design. Because all participants were attending schools primarily serving low-income families, we considered them at risk for mathematics underachievement. Children were randomly assigned either to the intervention condition or a “business as usual” control group. Dependent variables included a validated assessment of numeracy indicators as well as standardized measure of mathematics achievement. Because it has been shown that low-income children lag behind middle-income children in their use of adaptive calculation strategies (e.g., Jordan, et al., 2008), we also observed their problem solving methods on selected calculation problems.

Method

Participants

Participants were recruited from kindergarten classes in five schools serving high-risk children from low-income urban families. The percentage of children enrolled in the free/reduced lunch program ranged from 79% to 95% in each school, with the mean being 91%. All participating schools are in the same district in the Mid Atlantic region of the United States and are the lowest performing in the school district on the state mathematics tests at third grade. Informed consent letters were sent home with every full-day kindergartner ($N = 312$ children). One hundred fifty-one children (48%) returned the letters with consent. In one school, we obtained consent for more students than we were able to accommodate physically. In this case, 32 students were randomly selected for participation from a total of 49. Eight other students were not included because they moved out of the district before the study began, or because they were identified by their teachers as inappropriate for the study because of behavioral or attendance problems. One hundred and twenty-six participants remained, all of whom took the pretest. Out of those children, four moved out of the district before the end of the study period (two intervention and two control children) and one intervention child was chronically absent during the study period and could not complete the post testing. This left a total of 121 participants who completed the study. A power analysis for a repeated measures ANOVA was performed with $\alpha = .01$, an effect size of $\eta^2 = .2$, and a desired power of .95, which resulted in a required sample size of 90 students. Thus, the sample size of 120 students was more than adequate.

Of the final sample, 52 of the children were girls (43%) and 69 were boys (57%). Sixty-seven of the students were identified as African American (55%), 45 as Hispanic (37%), seven as Caucasian (6%), one as Asian, and one as bi-racial, all by teacher report. Thirty of the Hispanic students (25%) were identified as English Language Learners (ELL) and were

enrolled in designated ELL kindergarten classrooms. Demographics for the children in the intervention and control groups are summarized in Table 1.

In each of the five participating schools, about half of the participants were randomly selected for the intervention while the other half were assigned to a business as usual control group. Because the interventions were carried out in groups of 4, there were a few extra children in the various schools who were assigned to the control group, accounting for the unequal numbers in the intervention and control conditions. Participants also were stratified according to kindergarten class. That is, within each classroom, roughly one half the participants were randomly assigned to the intervention condition. Four of the classrooms (two in each of two schools) were designated ELL classrooms.

Measures

Number Sense—The *Number Sense Brief* (NSB) (Jordan, Glutting, Ramineni, & Watkins, 2010) is an untimed measure that takes approximately 20 minutes to administer. The items assess *counting skills* (e.g., knowledge of the count sequence to at least 30 and set enumeration) and *principles*, (e.g., stable order and one-to-one correspondence); *number recognition* (the ability to name written symbols, such as 13, 37, and 82); *number knowledge* (e.g., What number comes right after 7? Which number is bigger, 5 or 4?); *nonverbal addition/subtraction calculations* (e.g., The examiner places 2 disks in a horizontal line front of the child while saying, “See, here are two dots,” and then covers the disks with a cardboard check box lid. The examiner then puts out another disk and says, “See, here is one more dot, watch what I do,” and hides it under the same cover through an opening on the side of the box. The child is shown pictures of 4 sets of disks, each in a horizontal line, with different totals and is asked to point to the set that has the same number of items that is “hiding under the box.”); *addition/subtraction story problems* (e.g., orally presented as, “Jill has 2 pennies. Jim gives her 1 more penny. How many pennies does Jill have now?”); and *addition/subtraction number combinations* (orally presented as, “How much is $2 + 1$?”). For story problems and number combinations, children were provided with a pencil and paper well as a number list from 1 to 10. They were told they could use these tools, their fingers, or anything else they wanted to solve the problems.

Each item on the NSB was scored 0 (incorrect) or 1 (correct) with a total raw score of 42. Scoring is objective and thus there were not issues with inter-scorer reliability. A complete set of items for the NSB can be found in Jordan et al. (2009), although we added several more challenging number recognition (i.e., larger numbers) and counting items (i.e., higher counts), based on our pilot work to avoid ceiling effects and help discriminate more specifically between student abilities.

The NSB is internally consistent, with a coefficient alpha of at least .80 over five time points spanning kindergarten to the middle of first grade (Jordan et al., 2008). In addition, the NSB in kindergarten is highly predictive of mathematics achievement in first through at least third grade (Jordan et al., 2009; Jordan, et al., 2010).

Overt strategy use on NSB story problems and number combinations was recorded for each trial. Observable counting strategies were coded as finger counting, verbal or other observable counting, modeling and counting with paper and pencil, or use of a number list. If students used one or more of these strategies on a problem, it was coded as 1; no observable counting strategy was coded as 0. In the latter category, children may have used mental strategies, retrieved a fact from memory or simply guessed. Ambiguous strategies were discussed by the research team and resolved through group consensus.

Since *counting on* (counting up from one addend to the amount of the other addend) is a more sophisticated form of finger counting (Carpenter & Moser, 1984; Secada, Fuson, & Hall, 1983) and is considered a more efficient method than *counting all* (representing each addend with fingers and then counting all of them starting with one), we further coded 'counting all' vs. 'counting on' when children used their fingers on addition story problems and number combinations. Students were scored as counting-all when they re-counted the first addend to determine the sum after they had created both addends on their fingers. Students were scored as counting-on when they either counted the first addend and then counted up as they added the second addend (e.g. 3+2 would be counted "1,2,3.... 4,5), or if a student simply *said* the first addend and then counted up (e.g. 3+2 would be counted "3... 4,5).

Mathematics Achievement—General mathematics achievement was assessed using the *Woodcock-Johnson III Tests of Achievement* Form C Brief Battery (WJ): applied problems and calculation subtests (Woodcock, McGrew, & Mather, 2007). The applied problems subtest requires children to solve orally presented problems through the application of quantitative reasoning (starting with simple counting questions, then orally presented story problems with pictures, and finally orally presented story problems without pictures). It also assesses money and measurement concepts. The calculation subtest assesses computation in a written format with conventional symbols (problems are presented horizontally and vertically, starting with $2 + 2 = \square$). Internal reliability was above .90 in kindergarten for both subtests.

Attention—For each participant, kindergarten teachers were asked to complete the *SWAN Rating Scale* (Swanson, Schuck, Mann, Carlson, Hartman, et al., 2004), which includes 18 items from the *Diagnostic and Statistical Manual of Mental Disorders-IV* (American Psychiatric Association, 1994) criteria for Attention Deficit Hyperactivity Disorder for inattention. Teachers rate items on a 7 point Likert-scale ranging from -3 to +3 with zero being average and -3 being far below average ($\alpha > .9$).

Procedure

A pretest, immediate post test, and delayed post test design was used. Children were individually pretested on both the NSB and WJ mathematics achievement measure within a two-week window in November/early December of 2009. The intervention started in January of 2010 and was carried out in small groups of four children per instructor. The intervention groups met for three 30-minute sessions per week (Monday, Wednesday, and Friday) over an eight-week period for a total of 24 lessons. The interventions were carried out during a time when children were not receiving their regular mathematics or literacy instruction. Groups were seated at a small table, either in their classroom or an area just outside of the classroom.

During the week following the last lesson, children were individually post-tested with the NSB and the WJ measures. Approximately six weeks later, children were tested again with the same measures. Practice effects were not an issue, since all participating children had the same opportunity to gain from the repeated assessments.

All of the measures were administered by one of six university students studying education. All were fully trained in the testing procedures. The same researchers also carried out the interventions, although for the post-tests they did not test any children they taught. Although the assessments were given in English, every effort was made to ensure that all children understood the tasks they were asked to complete (e.g., repeating instructions if needed, pointing to printed numbers and pictures on the stimulus pages).

Intervention

The lessons were field tested in the winter of 2009 and revised in the summer and fall of the same year. All of the 24 lessons were carefully scripted.

Intervention Training—The scripts were presented to the student instructors in the fall of the school year along with the rationale for each activity. Important methods, including the use of pointing gestures, how to correct errors, and use of instructional materials were highlighted at weekly group training sessions. Pairs of instructors then practiced teaching the lessons to each other. Suggestions for improvements and clarifications were shared in group sessions

Fidelity of Implementation—To assess whether the intervention procedures were carried out as designed, three intervention lessons were audio-recorded for each of the six instructors. The recorded lessons occurred in the early, middle, and late stages of the program. Two research assistants checked the intervention recordings against the written lesson scripts, one of whom was not involved in carrying out the interventions. It was found that instructors followed the scripts carefully, with no substantive deviation. All lessons were completed as well as one hundred percent of the activities in the lessons.

Intervention Approach—The intervention was designed to augment the regular kindergarten mathematics program, *Math Trailblazers* (Teaching Integrated Math and Science Program, 2008) with small group instruction. The results of the field trials informed the choice of activities and the amount of time spent on each skill. Karen Fuson, an expert in early mathematics education, reviewed a preliminary version of the lessons and her suggestions were incorporated into the current version. Some of the activities were adapted from tasks found in the *Math Expressions* (Fuson, 2009) curriculum. Skills were reviewed incrementally over the course of the 24 lessons. A compare and contrast approach was used throughout the activities. For example, opposites such as before/after, addition/subtraction, $n + 1/n - 1$ were presented simultaneously. We monitored children's progress with informal assessments throughout the lessons in order to address individual needs of students. Review material was then tailored to the needs of individuals in the group. For example, if one child needed extra practice with recognition of numbers one through ten, the instructor would work with this child while the other children worked on number activity sheets.

Intervention Content—Intervention lessons were scripted with carefully chosen vocabulary (e.g. before, after, plus, minus, bigger, smaller, more, less, altogether, etc.). As new mathematics vocabulary was introduced, the lessons focused on the meaning of the word with respect to number. Because children were exposed to number recognition and oral counting activities each day during classroom calendar time, we did not emphasize these skills in the pilot version of the intervention. However, during the field trials, we found that although most children could recite the count sequence to 20, they could not recognize many two-digit numbers at posttest. Since the relation among number names, quantity, and the base-ten numeration system is a foundational number competency (National Council of Teachers of Mathematics, 2000), we revised the intervention to include these concepts as a key part of the intervention. Intervention activities are described below:

1. *Magic number*. Because of the English number naming system, the numbers 11–19 are particularly difficult for young children. We do not say “ten one, ten two” but rather “eleven and twelve”; and rather than “ten three” we say, “thirteen.” This makes learning these number names a challenge. In order to give children plenty of practice with these numbers, each session began with a new *magic number*, starting with 11. To emphasize the structure of the base-10 numeration system, the

instructor constructed the magic number using the '10' decade card and single digit overlays (Fuson, Grandau, & Sugiyama, 2001). For example, when the magic number was 11, the instructor placed the 1 card over the 0 in 10 and said, "See, 11 is 10 and 1 more. Eventually, the children picked out the digit card to put over the zero to make the new magic number. Then, the children counted in unison up to that number. When the number '20' was reached, attention was drawn to the tens place and 20 was shown to be two tens. Numbers after 20 were presented in the same manner as the 'teens', using the '20' decade card. When 30 was reached, the children were taught the remaining decades up to 90 and were directed to "build" various two digit numbers using the decade and single digit cards. Because of the difficult naming structure of the numbers 11–19, these numbers were reviewed daily.

2. *Number recognition game.* The magic number was added to the pile of number recognition cards for the daily number recognition game. Whoever got the magic number on their turn and named it correctly received a special sticker.
3. *Number sequencing.* Students worked together to put number cards into the proper sequence. Number cards were placed in rows and columns mimicking the 100's chart to highlight that 11 is 10 and 1, and 21 is 20 and 1, and so on (See Figure 1).
4. *Verbal subitizing.* Children were taught to recognize and name quantities up to four instantly, without counting.
5. *Finger use.* Children were taught to count on their fingers and to also make finger quantities to 5 quickly (without counting).
6. *Associating numeral to quantity.* Activities using a number list (see Figure 1) and chips supported the learning of counting principles related to one-to-correspondence and cardinality. Since we were looking at discrete quantities, a number list was more appropriate than a number line (which starts at 0 and includes numbers 'between' the counting numbers).
7. *Number plus (or minus) one principle.* Chips were used with the number list to illustrate that the next number in the count sequence is *always* one more than the previous number. The $n+1$ principle leads into the introduction of before and after numbers as $n-1$ and $n+1$, respectively. In the field trial, the numbers *after* were presented first and then, numbers *before*. Once students learned the 'after' numbers, it was hard to then teach them the 'before' numbers. They seemed to fixate on the 'after' numbers, which reflects the findings of Baroody, et al. (2009). In an attempt to avoid this problem, 'before' and 'after' numbers were taught simultaneously through various number list activities.
8. *Number comparisons.* A cardinality chart was used to support children's understanding of bigger and smaller numbers (see Figure 1). The number with the most dots is the bigger of two numbers. The top row of the cardinality chart looks like the number list to reinforce the connection between the count sequence and quantity. Children practiced identifying bigger and smaller numbers through number list and cardinality chart activities.
9. *Part-whole relationships.* Number partners are a pair of numbers whose sum is the given number. Activities using a row of dots and a pencil separator allowed students to discover partners for numbers 2 through 5. Cards were made for each set of partners (see Figure 1). By rotating the partner card 180 degrees, the instructor was able to demonstrate the commutative property of addition. Partner card activities included connecting partners to written combinations with Arabic numbers, both addition and subtraction. Children were shown subtraction problems

in the part-whole relationship by having the instructor cover up one part of the partner dot card. This conceptual representation supports children's use of counting up from the subtrahend to solve subtraction problems, a method found easier and more accurate than counting down from the minuend (Fuson & Fuson, 1992)

10. *Using counting to solve problems.* Children were given opportunities to solve story problems with several strategies, including fingers and writing down tally marks or circles. Children were explicitly shown how to count-on from an addend (counting on), although they were not discouraged from counting all of their representations in both sets (counting all) if counting on was difficult for them. Children were also encouraged to connect quantities to real-world problems using a magnetic story board and magnetic objects, such as apples or farm animals.

During the field trial, many of the intervention children showed little or no change in their ability to solve basic number combinations such as, "How much is 3 and 2?" Surprisingly, the intervention group did not apply the strategies they used for solving problems that referred to objects to number combinations with no object referents. In the present study, we helped children make connections between story problems and number combinations. Every time a story problem was given, the corresponding combination was presented to or "found" by the children. Students were also asked to find the partner card that matched the story problem or number combination and vice versa. Although the importance of fact fluency was not being minimized, children were encouraged to be resourceful and to use strategies to solve problems they had not yet memorized.

11. *Number board game.* At the end of each session children played the *Great Race Game*, adapted from Ramani and Siegler (2008). The game served as a reward for the children working hard during the session. The game board was a colorful number list with numbers one to ten. Each number was enclosed in a square and a starting place was marked at just before the number one. To determine the number of spaces to move, the child used a spinner divided into two regions, one region containing the number 'one' and the other region containing the number 'two.' After the child spun a 'one' or a 'two', they were required to 'say' their move using a prescribed format that encouraged 'counting on.' For example, if the child was on three and came up with a two on the spinner, he or she would say, "I'm on three; I need to move two more." Then, as they moved their piece they would say, "four, five" as they landed on those numbers. One change was added to the original game. In keeping with our instructional strategy of comparing and contrasting (i.e., plus vs. minus, before vs. after), a spinner with "+1", "-1", "+2", "-2" was used later in the lessons and children were instructed in moving forwards and backwards. The vocabulary words (plus, minus, before, after) that had been introduced in previous lessons were used in the game to reinforce the concepts in a different venue. For example, if a child was on three and spun "+2", when the child landed on five, the instructor would say, "That's right, five is two after three," or "That's right, three plus two makes 5."

Results

Table 2 provides mean raw scores and standard deviations on the NSB by group (intervention vs. control) and time period (pretest, post test, and delayed post test). Figure 2 provides a visual representation of the data, and it reveals that the intervention group showed larger growth on scores from the NSB than children in the control group. Over the three NSB test points, the control children went from 50% to 68% correct while the intervention children went from 45% to 74% correct. NSB subarea means (i.e., counting skills, counting

principles, number recognition, number knowledge, nonverbal calculation, story problems, and number combinations) also are presented in Table 2. Mean raw and percentile (based on national kindergarten norms) scores on the WJ achievement test by group and time are presented in Table 3.

Preliminary analyses revealed no group interaction effects involving language status (ELL vs. non-ELL) or gender. Moreover, there was no significant difference between the mean SWAN teacher rating scores of the groups, suggesting that the intervention ($M = .50$, $SD = 2.33$) and control ($M = .35$, $SD = 2.2$) children exhibit similar levels of attention in school. Therefore, these variables were excluded as variables in subsequent analyses. The deletions, in turn, functioned to make our models more parsimonious and easier to interpret.

A series of one-way ANCOVAs were conducted to test whether the mean gains between pretest and immediate posttest and delayed posttest for total and subarea¹ scores from the NSB and Woodcock-Johnson (WJ) Achievement Test differed between groups (intervention group vs. controls). In addition to p values, effect sizes are reported using r^2 coefficients.

Although children were randomly assigned to the intervention and control groups, pretest scores from the NSB and/or pretest scores from WJ served as the covariate(s). The covariate(s) served the dual purposes of: (a) minimizing any potential confounding that might be attributable to prior mathematics knowledge between the two groups and (b) reducing unexplained variance, and thereby, increasing the power of the analyses to detect treatment effects (Field, 2009; Maxwell & Delaney, 2004). Three combinations of covariates were employed: (a) pretest scores from the NSB, (b) pretest scores from WJ, and (c) pretest scores from both the NSB and WJ. The reason for including both a variety and combination of covariates is that the processes and strategies subsumed under the construct of early mathematics knowledge are broad and span a variety of tasks. At pretest the correlation between the NSB and the WJ total score was .68.

Table 4 presents p values and effect sizes. Effect sizes are presented only for analyses where group differences reached statistical significance. Results were consistent across the ANCOVA models for the NSB and associated subareas; in all instances, the intervention group obtained significantly higher and meaningful adjusted outcome scores at posttest as well as at delayed posttest. For the WJ, the results were significant at posttest but not a delayed posttest and only for the calculation problems subtest. There were not significant group differences for the applied problems subtest.

To explore what may have led to children's growth in calculation on the NSB in particular, the frequency with which children used adaptive counting strategies on story problems and number combinations was analyzed. At pretest, strategy use was rarely observed in any participating children. Table 5 provides the means and standard deviations (by group and time) for the number of times a counting strategy was used on story problems and number combinations, respectively. A significant group by time interaction for both story problems ($F(2, 118) = 15.39$, $p < .001$) and number combinations ($F(2, 118) = 5.61$, $p = .005$) showed that the intervention children grew more than the control children in frequency of strategy use with large ($\eta^2 = .21$) and medium to large ($\eta^2 = .09$) effect sizes on story problems and number combinations, respectively. Strategy use was significantly correlated with accuracy on story problems and number combinations for both groups at every time point. The correlation between use of counting strategies and accuracy for the control group was .74 at pretest, .82 at posttest, and .78 at delayed posttest, and the correlation for the

¹Subareas of counting skills, counting principles, and nonverbal calculation were not included because of weak internal reliability, $< .70$.

intervention group it was .41 at pretest, .70 at posttest, and .81 at delayed posttest. We also examined whether children used *counting-on* strategies when counting with their fingers on addition calculations as opposed to *counting-all*. When children were coded as using their fingers for either a story problem or a number combination, we found that for the control group, 11% were observed using counting-on for more than one trial at pretest, 7% at post test, and 14% at delayed post test. For the intervention children, 5% were observed using counting-on for more than one trial at pretest, 20% at post test, and 27% at delayed post test.

Discussion

The primary aim of this study was to test the effectiveness of a purposeful number sense intervention for kindergartners who are at risk for developing mathematics learning difficulties. The intervention was based on previous work demonstrating that many low-income children show deficiencies in number sense (e.g., Jordan et al., 2006) and that kindergarten number sense is highly predictive of meaningful mathematics outcomes in elementary school. The intervention was carried out in small groups and consisted of three 30-minute sessions per week over eight weeks. Children were randomly assigned either to the intervention condition or a business as usual control. Although both groups made gains in number sense over the course of the study, the intervention children made larger gains than the control children. Notably, the intervention effects held six weeks after the intervention was carried out. Given that kindergarten and first-grade number sense predicts calculation fluency in second grade (Locuniak & Jordan, 2008), the presence of a mathematics learning disability in third grade (Mazzocco & Thompson, 2005), and success rate on a high stakes state mathematics test in third grade (Jordan et al., 2010), the finding that it can be increased in high-risk children with a relatively short intervention is encouraging.

To explain the results, we compared group performance on different numeracy topics on the NSB. We were not surprised that children in the intervention group made more gains than the controls in number recognition since this skill was targeted during our activities. It is noteworthy, however, that many of the intervention children were able to recognize larger numbers not presented in our activities. Although all children practiced number recognition each day in their classrooms during calendar time, teachers reported giving little or no instruction in the base-ten structure of two-digit numbers. That the intervention children benefited from focused base-ten instruction indicates that this approach may be a viable way to give them a much needed head start for first-grade mathematics.

Number knowledge is another area where the intervention children showed a significant difference in growth relative to those in the control group. We taught relational concepts (before/after, bigger/smaller, closer to) using a compare/contrast method, presenting opposing concepts simultaneously. This method prevented children from fixating on whichever idea was presented first. A continuing problem for some students, though, was interchanging “before” and “after” during oral activities. They would point with their finger and say, “This way or this way?” However, when presented with a written task consisting of a single digit numeral with a blank on either side, they had no trouble filling in the correct before and after numbers. Competence on such paper and pencil activities, which are common on group-administered math assessments, may not represent complete number knowledge.

Intervention children also showed more growth than control children on story problems and number combinations. Counting strategies helped children in both groups solve story problems and number combinations more accurately. Although the intervention group started out below control group with respect to the effectiveness of their strategy use, by

delayed post test there was no difference between the groups in how often using a strategy produced the correct answer - approximately 80% of the time. The intervention children tended to use counting-on strategies more often than children in the control condition. This supports the findings of Secada, et al. (1983), that counting-on can be encouraged by instruction in counting subskills. Through direct instruction, children can be made aware that the number name of an addend can represent the cardinal value of the set, but it can also be the count number used to start the counting of the addition of the second addend to make the sum. This skill also allows children to use *counting-up* as a strategy for solving subtraction problems, a strategy that has shown to be more effective than counting down (Fuson & Fuson, 1992; Fuson & Willis, 1988).

The counting skills tasks were not reliable, partially due to ceiling performance by most children on set enumeration. For example, children were asked to enumerate a set of five stars (greater than 95% correct at pretest and 100% at post test for both groups) and to give the examiner four dots (greater than 92% correct at pretest and 100% at post test for both groups). The only observed change over time was how high the children could count orally, where both groups grew significantly and at a similar rate, indicating that the intervention did not add to these abilities. At delayed post-test, about 91% of the children in both groups could count to 20. Only the growth in “counting to 30” (Control: 50.8% to 73.8%; Intervention: 41.1% to 73.2%) favored the intervention group, which may indicate that the intervention helped them catch up to the control group by delayed post-test.

Performance on counting principles items was not a reliable indicator of growth. Borrowing from previous studies (e.g., Geary, Hamson, & Hoard, 2000), children were asked to watch a finger puppet count a horizontal row of yellow and blue dots and then to indicate if the puppet counted in a way that was “OK” or “not OK or wrong”. The puppet counted in ways that were correct, incorrect (i.e., double counted the first dot), or unusual but correct (counted right to left; counted all the blue, then all the yellow dots). Recently, LeFevre et al. (2006) described a U-shaped trajectory for development on these types of tasks. On average, preschool children are accepting of unusual but correct counts. During kindergarten, however, as children begin to grow in their ability to count in conventional contexts, they become less accepting of unusual counts and prefer counting be done the “right way.” By second grade, they are more flexible and accept unusual or nonconventional counts. Our data showed that from pretest to final posttest, children in both groups declined in their ability to recognize unusual counts as correct (i.e., that counting the yellow dots then the blue dots is “OK”), confirming LeFevre et al.’s findings.

On the general mathematics achievement test (WJ), the intervention children outperformed controls on the Calculation subtest when we held initial number sense constant. This finding suggests that children transferred the knowledge they gained during the intervention to less familiar, more conventional written formats. Although encouraging, the group effects diminished by delayed posttest. Analysis of the items in the Applied Problems subtest, where no group effects were observed, revealed that it captured only two of the seven NSB topics (counting skills and word problems), suggesting it may have been less sensitive to what was taught in the intervention. Nevertheless, it is of some concern that the experimental children did not score better on this measure, given the attention that we devoted to problem solving more generally. A closer look at the word problems on the WJ revealed that the majority of story problems provided pictorial representations (e.g., The child is shown picture of 2 frogs sitting on a rock with another one jumping to the rock, and the examiner says, “Two frogs are sitting on the shore. Another frog jumps out of the water and joins them. How many frogs are now on the shore?”), which were relatively easy for most children to solve. When the pictorial representations stopped, the story problems involved situations that were less typical than those provided in our intervention and also

involved larger numbers (e.g., “There were six dishes on the dinner table. Chong places two in the sink. How many dishes were still on the table?”). Several of the WJ word problems also required children to know the value of coins, which we did not address in the study. It should also be noted that children were not prompted to use counting strategies on the WJ as they were on the NSB, nor did they have access to a number list or pencil and paper. Future iterations of our intervention should provide children with opportunities to apply their knowledge of addition and subtraction to a wider variety of contexts.

Informal debriefing sessions with participating teachers at the completion of the study indicated that the intervention supported classroom learning. Teachers reported that they had supplemented the prescribed kindergarten mathematics curricula because of recent changes in the school district’s kindergarten standards and assessments, which now included join addition story problems and combinations. The supplemental classroom activities were similar to those used in our intervention (e.g., solving story problems). It was the teachers’ impression that children in the intervention group were able to access the lessons more readily than the control children. These observations are in keeping with Fuchs, Fuchs, Craddock, Hollenbeck, Hamlett, and Schatschneider (2008) who showed that supplemental interventions are more effective when they are aligned with what takes place in the classroom.

A limitation of the study is the lack of a small group intervention comparison group, one that did not involve numbers. It is possible (although not likely) that the number sense gains seen in the intervention group were due to special treatment more generally, rather than to the specific number activities. We felt it important, however, to determine initially whether we could boost children’s number sense performance relative to a business as usual control, and the finding that the intervention children changed most in the areas we emphasized (e.g., number recognition, number knowledge, calculation) argues against Hawthorne effects (Sutter, 2006). In follow-up studies, however, we plan to include a general intervention condition, carried out in small groups, for comparison to the number sense condition. It would also be useful to carry out a contrast number-related intervention such as one that emphasizes rote skill development of number skills (e.g., number recognition and combinations flash cards) rather than connected number and operational knowledge. Additionally, further research should test the intervention with children of all social classes who are screened in early mathematics skills and determined to be at risk for learning disabilities.

Building on other investigations (e.g., Baroody et al., 2009; Chard et al., 2008; Ramani & Siegler, 2008), the present randomized controlled study demonstrates that key areas of number sense can be boosted in kindergartners with established risk for mathematics difficulties or disabilities, many who come to school with far fewer learning experiences than their middle-income counterparts. These gains were successfully captured on a number sense assessment tool that is sensitive to short-term progress in kindergarten and there was some transfer to more conventional written calculation tasks. Although most children seemed to gain from their regular mathematics curriculum, the intervention provides them with added benefits in a relatively short time period. This type of number sense intervention, which can easily be implemented in kindergarten classrooms, holds promise for evidence based response- to-intervention (RTI) service delivery models in schools (Fuchs, Fuchs, Compton, Bryant, Hamlett, & Seethaler, 2007; Johnson, Mellard, Fuchs, & McKnight, 2006). The intervention could be used for time-limited prevention of mathematics difficulties, or it could be expanded beyond eight weeks for more intensive ongoing assistance, with the aim of preparing children for success in primary-school mathematics.

Acknowledgments

This research was supported by Grant # HD059170 from the Eunice Kennedy Shriver National Institute of Child Health and Human Development.

References

- American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders DSM-IV. Arlington, VA: American Psychiatric Publishing, Inc.; 1994.
- Baroody AJ. The development of counting strategies for single-digit addition. *Journal for Research in Mathematics Education*. 1987; 18(2):141–157.
- Baroody AJ, Eiland M, Thompson B. Fostering at-risk preschoolers' number sense. *Early Education & Development*. 2009; 20(1):49.
- Baroody, AJ.; Lai, M-L.; Mix, KS. The development of young children's early number and operation sense and its implications for early childhood education. In: Spodek, B.; Saracho, O., editors. *Handbook of research on the education of young children*. Mahwah, NJ: Lawrence Erlbaum Associates; 2006. p. 187–221.
- Carpenter TP, Moser JM. The Acquisition of Addition and Subtraction Concepts in Grades One through Three. *Journal for Research in Mathematics Education*. 1984; 15(3):179–202.
- Carpenter TP, Hiebert J, Moser JM. The Effect of instruction on children's solutions of addition and subtraction word problems. *Educational Studies in Mathematics*. 1983; 14(1):55–72.
- Case, R.; Griffin, S. Child cognitive development: The role of central conceptual structures in the development of scientific and social thought. In: Hauert, EA., editor. *Developmental psychology: Cognitive, perceptuo-motor, and neurological perspectives*. North-Holland: Elsevier; 1990. p. 193–230.
- Chard DJ, Baker SK, Clarke B, Jungjohann K, Davis K, Smolkowski K. Preventing Early Mathematics Difficulties: The Feasibility of a Rigorous Kindergarten Mathematics Curriculum. *Learning Disability Quarterly*. 2008; 31(1):11–20.
- Clarke B, Shinn MR. A preliminary investigation into the identification and development of early mathematics curriculum-based measurement. *School Psychology Review*. 2004; 33(22):234–248.
- Clements DH, Sarama J. Experimental evaluation of the effects of a research-based preschool mathematics curriculum. *American Educational Research Journal*. 2008; 45(2):443–494.
- Cohen, J. *Statistical power analysis for the behavioral sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum; 1988.
- Duncan GJ, Dowsett CJ, Claessens A, Magnuson K, Huston AC, Klebanov P, Pagani Linda S, Japel C. School readiness and later achievement. *Developmental Psychology*. 2007; 43(6):1428–1446. [PubMed: 18020822]
- Feigenson L, Dehaene S, Spelke E. Core systems of number. *TRENDS in Cognitive Sciences*. 2004; 8(7):307–314. [PubMed: 15242690]
- Field, A. *Discovering statistics using SPSS*. 3rd ed. London: Sage; 2009.
- Fuchs LS, Fuchs D, Compton DL, Bryant JD, Hamlett CL, Seethaler PM. Mathematics screening and progress monitoring at first grade: Implications for responsiveness to intervention. *Exceptional Children*. 2007; 73(3):311–330.
- Fuchs LS, Fuchs D, Craddock C, Hollenbeck KN, Hamlett CL, Schatschneider C. Effects of small-group tutoring with and without validated classroom instruction on at-risk students' math problem solving: Are two tiers of prevention better than one? *Journal of Educational Psychology*. 2008; 100(3):491–509. [PubMed: 19122881]
- Fuchs LS, Fuchs D, Stuebing K, Fletcher JM, Hamlett CL, Lambert WE. Problem solving and calculation skill: Shared or distinct aspects of mathematical cognition? *Journal of Educational Psychology*. 2008; 100:30–47. [PubMed: 20057912]
- Fuson, KC. *Children's Counting and Concepts of Number*. New York: Springer-Verlag; 1988.
- Fuson, KC. *Math expressions*. Orlando, FL: Houghton Mifflin Harcourt; 2009.
- Fuson KC, Fuson AM. Instruction supporting children's counting on for addition and counting up for subtraction. *Journal for Research in Mathematics Education*. 1992; 23(1):72–78.

- Fuson KC, Grandau L, Sugiyama PA. Achievable numerical understandings for all young children. *Teaching Children Mathematics*. 2001; 7(9):522–526.
- Fuson KC, Willis GB. Subtracting by counting up: More evidence. *Journal for Research in Mathematics Education*. 1988; 19(5):402–420.
- Geary DC, Hamson CO, Hoard MK. Numerical and arithmetical cognition: A longitudinal study of process and concept deficits in children with learning disability. *Journal of Experimental Child Psychology*. 2000; 77(3):236–263. [PubMed: 11023658]
- Gelman, R.; Gallistel, CR. *The child's understanding of number*. Cambridge, MA: Harvard University Press; 1978.
- Gersten R, Jordan NC, Flojo JR. Early identification and interventions for students with mathematics difficulties. *Journal of Learning Disabilities*. 2005; 38(4):293–304. [PubMed: 16122059]
- Ginsburg, HP. *Children's arithmetic*. Austin, TX: PRO-ED; 1989.
- Ginsburg HP, Lee JS, Boyd JS. *Mathematics education for young children: What it is and how to promote it*. Social Policy Report. 2008; 22(Number 1)
- Griffin, S. The development of math competence in the preschool and early school years: Cognitive foundations and instructional strategies. In: Roher, JM., editor. *Mathematical Cognition*. Greenwich, CT: Information Age Publishing; 2002. p. 1-32.
- Griffin S. Building number sense with Number Worlds: A mathematics program for young children. *Early Childhood Research Quarterly*. 2004; 19:173–180.
- Griffin S, Case R. Re-thinking the primary school math curriculum: An approach based on cognitive science. *Issues in Education*. 1997; 3(1):1–49.
- Hiebert J. Children's mathematics learning: The struggle to link form and understanding. *The Elementary School Journal*. 1984; 84(5):496–513.
- Huttenlocher J, Jordan NC, Levine SC. A mental model for early arithmetic. *Journal of Experimental Psychology: General*. 1994; 123:284–296. [PubMed: 7931093]
- Johnson E, Mellard DF, Fuchs D, McKnight MA. Responsiveness to intervention (RTI): How to do it. [RTI Manual]: National Research Center on Learning Disabilities. 2006
- Jordan NC, Glutting J, Ramineni C. The importance of number sense to mathematics achievement in first and third grades. *Learning and Individual Differences*. 2009; 20(2):82–88. [PubMed: 20401327]
- Jordan NC, Glutting J, Ramineni C, Watkins MW. Validating a number sense screening tool for use in kindergarten and first grade: Prediction of mathematics proficiency in third grade. *School Psychology Review*. 2010; 39(2):181–185.
- Jordan NC, Huttenlocher J, Levine SC. Differential calculation abilities in young children from middle- and low-income families. *Developmental Psychology*. 1992; 28(4):644–653.
- Jordan NC, Kaplan D, Locuniak M, Ramineni C. Predicting first-grade math achievement from developmental number sense. *Learning Disabilities Research & Practice*. 2007; 22(1):36–46.
- Jordan NC, Kaplan D, Nabors Olah L, Locuniak MN. Number sense growth in kindergarten: A longitudinal investigation of children at risk for mathematics difficulties. *Child Development*. 2006; 77(1):153–175. [PubMed: 16460531]
- Jordan NC, Kaplan D, Ramineni C, Locuniak MN. Development of number combination skill in the early school years: When do fingers help? *Developmental Science*. 2008; 11(5):662–668. [PubMed: 18801121]
- Jordan NC, Kaplan D, Ramineni C, Locuniak MN. Early math matters: Kindergarten number competence and later mathematics outcomes. *Developmental Psychology*. 2009; 45(3):850–867. [PubMed: 19413436]
- Jordan NC, Levine SC. Socioeconomic variation, number competence, and mathematics learning difficulties in young children. *Developmental Disabilities Research Reviews*. 2009; 15(1):60–68. [PubMed: 19213011]
- Juel C. Learning to read and write: A longitudinal study of 54 children from first through fourth grades. *Journal of Educational Psychology*. 1988; 80(4):437–447.
- Keith, TZ. *Multiple regression and beyond*. Boston: Pearson; 2006.

- Klibanoff RS, Levine SC, Huttenlocher J, Vasilyeva M, Hedges LV. Preschool children's mathematical knowledge: The effect of teacher "Math Talk". *Developmental Psychology*. 2006; 42(1):59–69. [PubMed: 16420118]
- Lee, VE.; Burkam, DT. *Inequality at the Starting Gate: Social Background Differences in Achievement as Children Begin School*. Washington, DC: Economic Policy Institute; 2002.
- LeFevre JA, Smith-Chant BL, Fast L, Skwarchuk SL, Sargla E, Arnup JS, Kamawar D. What counts as knowing? The development of conceptual and procedural knowledge of counting from kindergarten through grade 2. *Journal of Experimental Child Psychology*. 2006; 93:285–303. [PubMed: 16360166]
- Lembke E, Foegen A. Identifying Early Numeracy Indicators for Kindergarten and First-Grade Students. *Learning Disabilities Research & Practice*. 2009; 24(1):12–20.
- Levine SC, Jordan NC, Huttenlocher J. Development of calculation abilities in young children. *Journal of Experimental Child Psychology*. 1992; 53:72–103. [PubMed: 1545190]
- Locuniak MN, Jordan NC. Using kindergarten number sense to predict calculation fluency in second grade. *Journal of Learning Disabilities*. 2008; 41(5):451–459. [PubMed: 18768776]
- Malofeeva E, Day J, Saco X, Young L, Ciancio D. Construction and evaluation of a number sense test with Head Start children. *Journal of Educational Psychology*. 2004; 96(4):648–659.
- Maxwell, SE.; Delaney, HD. *Designing experiments and analyzing data: A model comparison perspective*. 2nd ed. Mahwah, NJ: Lawrence Erlbaum Associates; 2004.
- Mazzocco MM, Thompson RE. Kindergarten predictors of math learning disability. *Learning Disabilities Research and Practice*. 2005; 20(3):142–155. [PubMed: 20084182]
- Methe SA, Hintze JM, Floyd RG. Validation and decision accuracy of Early Numeracy Skill Indicators. *School Psychology Review*. 2008; 37(3):359–373.
- National Center for Education Statistics. *The Nations Report Card: Mathematics 2009* (No. NCES 2010-451). Washington, DC: 2009.
- National Council for Teachers of Mathematics (NCTM). *Principles and standards for school mathematics*. Reston, VA: National Council of Teachers of Mathematics; 2000.
- National Institute of Child Health and Development. *Report of the National Reading Panel. Teaching children to read: An evidence-based assessment of the scientific research literature on reading and its implications for reading instruction* (NIH Publication No. 00-4769). Washington, DC: U. S. Government Printing Office; 2000.
- National Mathematics Advisory Panel. *Foundations for success: The final report of the National Mathematics Advisory Panel*. Washington, DC: U. S. Department of Education; 2008.
- National Research Council. *Mathematics learning in early childhood: Paths toward excellence and equity*. Washington, DC: The National Academies Press; 2009.
- Ramani GB, Siegler RS. Promoting broad and stable improvements in low-income children's numerical knowledge through playing number board games. *Child Development*. 2008; 7(2):375–394. [PubMed: 18366429]
- Rousselle L, Palmers E, Noel M-P. Magnitude comparison in preschoolers: What counts? Influence of perceptual variables. *Journal of Experimental Child Psychology*. 2004; 87(1):57–84. [PubMed: 14698689]
- Rousselle L, Noel M-P. Basic numerical skills in children with mathematics learning disabilities: A comparison of symbolic vs. non-symbolic number magnitude processing. *Cognition*. 2007; 102:361–395. [PubMed: 16488405]
- Secada WG, Fuson KC, Hall JW. The transition from counting-on to counting-all in addition. *Journal for Research in Mathematics Education*. 1983; 14(1):47–57.
- Siegler RS. Improving the numerical understanding of children from low-income families. *Child Development Perspectives*. 2009; 3(2):118–124.
- Starkey P, Klein A, Wakeley P. Enhancing young children's mathematical knowledge through a pre-kindergarten mathematics intervention. *Early Childhood Research Quarterly*. 2004; 19:99–120.
- Sutter, WN. *Introduction to educational research: A critical thinking approach*. Thousand Oaks, CS: Sage; 2006.

- Swanson, J.; Schuck, S.; Mann, M.; Carlson, C.; Hartman, K.; Sergeant, J., et al. Categorical and dimensional definitions and evaluations of symptoms of ADHD: the SNAP and SWAN rating scales. University of California, Irvine: 2006.
- VanDerHeyden AM. Determining early mathematical risk: Ideas for extending the research. *School Psychology Review*. 2010; 39:196–202.
- VanDerHeyden AM, Broussard C, Cooley A. Further development of measures of early math performance for preschoolers. *Journal of School Psychology*. 2006; 44(6):533–553.
- Woodcock, RW.; McGrew, KS.; Mather, N. Woodcock-Johnson III. Itasca, IL: Riverside; 2007.

DECADE and UNITS CARDS

NUMBER LIST

CARDINALITY CHART

PARTNER CARDS for FOUR

Figure 1.
Materials used in the number sense intervention.

Estimated Marginal Means of NumberSense

Figure 2.

The intervention group was below the control group at pretest but showed significantly greater gains at posttest and was able to maintain the difference at delayed posttest

Table 1

Demographics by Group

	<u>Gender</u>		<u>Ethnicity</u>			<u>Percent ELL</u>	<u>Age as of Sept 1</u>	
	Male	Female	AA	H	C	Other	Mean	SD
Control	35	30	35	25	3	2	66 mo	4.2
Intervention	34	22	32	20	4	0	66 mo	4.1
Total	69	52	67	45	7	2	66 mo	4.0

Note. AA= African American, H=Hispanic, C=Caucasian, Other = 1 Asian and 1 Bi-racial child.

Table 2

Number Sense Brief Mean Raw Scores by Group at Each Time Point

	N	<u>Pretest</u>		<u>Posttest</u>		<u>Delayed</u>	
		M	SD	M	SD	M	SD
NSB Total Score	42						
Control		21.09	7.54	26.40	8.04	27.68	8.28
Intervention		19.45	6.04	29.45	6.21	30.93	6.30
NSB Subarea							
Counting Skills	6						
Control		4.89	1.36	5.49	.92	5.58	0.73
Intervention		4.75	1.28	5.59	.65	5.55	0.66
Counting Principles	4						
Control		2.63	0.84	2.78	.84	2.91	0.79
Intervention		2.82	0.79	2.64	.70	2.80	0.88
Number Recognition	8						
Control		3.29	2.30	4.91	2.32	5.31	2.50
Intervention		2.75	1.94	5.95	1.68	6.34	1.68
Number Knowledge	9						
Control		4.92	2.00	5.71	2.34	5.69	2.15
Intervention		4.55	2.15	6.52	1.74	6.57	1.85
Nonverbal Calculation	4						
Control		2.62	1.23	3.12	0.98	3.31	0.87
Intervention		2.68	1.06	3.05	0.96	3.18	0.86
Story Problems	5						
Control		1.40	1.45	2.31	1.67	2.40	1.78
Intervention		1.02	1.12	3.20	1.73	3.27	1.67
Number Combinations	6						

	<u>Pretest</u>			<u>Posttest</u>			<u>Delayed</u>		
	N	M	SD	N	M	SD	N	M	SD
Control		1.34	1.86	2.08	2.17	2.48	2.21		
Intervention		0.88	1.11	2.50	1.95	3.21	2.22		

Note. N = number of items in each category on the NSB.

Woodcock Johnson Math Scores by Subtest and Group at Each Time Point. Corresponding Mean percentile scores, based on national kindergarten norms, are presented in parentheses.

Table 3

WJ Subtest	Pretest		Posttest		Delayed	
	M	SD	M	SD	M	SD
Applied Problems						
Control	9.69 (38)	3.48	11.54 (44)	3.16	12.05 (43)	2.85
Intervention	9.41 (37)	2.63	11.80 (46)	2.36	11.73 (41)	2.49
Calculation						
Control	1.42 (22)	2.24	2.42 (32)	3.00	3.11 (35)	3.02
Intervention	0.89 (15)	1.42	2.73 (42)	2.04	3.46 (40)	2.77
Total Score						
Control	11.11	5.08	13.95	5.30	15.15	5.12
Intervention	10.30	3.30	14.54	3.96	15.20	4.50

Note. Percentiles are not given for Total Score because the Total Math Score includes a third fluency test that we deemed as inappropriate for kindergarten.

Table 4

Analysis of Covariance Results Evaluating Intervention Effectiveness

Dependent Variable	Covariate					
	NSB Pretest Alone	WJ Total Pretest Alone	Both NSB & WJ Total Pretest	<i>p</i>	<i>R</i> ²	<i>R</i> ²
Total Score NSB posttest	.001	.302	.001	.266	.001	.304
Total Score NSB delay	.001	.299	.001	.267	.001	.301
Number Recognition NSB posttest	.001	.319	.001	.280	.001	.320
Number Recognition NSB delay	.001	.302	.002	.266	.001	.302
Number Knowledge NSB posttest	.001	.267	.002	.241	.001	.270
Number Knowledge NSB delay	.001	.282	.001	.260	.001	.284
Story Problems NSB posttest	.001	.314	.001	.299	.001	.316
Story Problems NSB delay	.001	.299	.001	.281	.001	.300
Number Combinations NSB posttest	.014	.181	.033	.159	.009	.184
Number Combinations NSB delay	.002	.235	.009	.209	.009	.209
Total Score from WJ posttest	.021	.180	<i>Ns</i>		.014	.160
Total Score from WJ delay	<i>ns</i>	<i>Ns</i>	<i>Ns</i>		<i>ns</i>	
AP Score from WJ posttest	<i>ns</i>	<i>Ns</i>	<i>Ns</i>		<i>ns</i>	
AP Score from WJ delay	<i>ns</i>	<i>Ns</i>	<i>Ns</i>		<i>ns</i>	
CP Score from WJ posttest	.004	.227	.013	.204	.003	.229
CP Score from WJ delay	<i>ns</i>	<i>Ns</i>	<i>Ns</i>		<i>ns</i>	

Note. NSB = Number Sense Brief; WJ = Woodcock-Johnson; AP = Applied problems; CP = Calculation Problems. Effect sizes (i.e., standardized beta coefficients) are presented only in instances where results were statistically significant; *ns* = not statistically significant.

*f*² *R*² represents multiple correlation coefficients squared. Values equal to .02 are considered small but meaningful effect sizes; those at .13 are considered to be moderate effect sizes, and those at or above .25 are considered to be large effect sizes (cf. Cohen, 1988, pp. 413–414). *R*² statistics were originally derived as standardized beta coefficients and converted using criteria established by Keith (2006).

Table 5

Frequency of Strategy Use

Subarea	Pretest		Posttest		Delayed	
	M	SD	M	SD	M	SD
Story Problems						
Control	1.02	1.60	1.88	2.03	1.85	2.00
Intervention	0.82	1.67	3.96	1.92	3.46	2.09
Number Combinations						
Control	0.97	2.05	1.57	2.18	1.63	2.11
Intervention	0.64	1.67	2.71	2.40	2.59	2.49

Note. Strategies include finger or other observable counting, drawing, or use of a number list.