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The importance of number sense to mathematics achievement in first and third grades☆

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ABSTRACT

Children's symbolic number sense was examined at the beginning of first grade with a short screen of competencies related to counting, number knowledge, and arithmetic operations. Conventional mathematics achievement was then assessed at the end of both first and third grades. Controlling for age and cognitive abilities (i.e., language, spatial, and memory), number sense made a unique and meaningful contribution to the variance in mathematics achievement at both first and third grades. Furthermore, the strength of the predictions did not weaken over time. Number sense was most strongly related to the ability to solve applied mathematics problems presented in various contexts. The number sense screen taps important intermediate skills that should be considered in the development of early mathematics assessments and interventions.

1. Introduction

Mathematics achievement is a key educational concern in the United States. Competence in mathematics is critical to the workforce in STEM (science, technology, engineering, and mathematics) disciplines and to international leadership. Although there is an upward trend in average mathematics test scores in elementary and middle school (e.g., National Assessment of Educational Progress, 2008), U.S. students still lag behind their counterparts in many other industrialized nations (National Mathematics Advisory Panel, 2008). Moreover, within the school population, there are large individual differences in mathematics achievement associated with socioeconomic status (Lubienski, 2000), home experiences (Blevins-Knabe & Musun-Miller, 1996), culture and language (Miller & Stigler, 1987; Miura, 1987), and learning abilities (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007).

Although considerable attention has been devoted to mathematics achievement in elementary and secondary schools, foundations for mathematics learning are established much earlier (Clements & Sarama, 2007). There is good reason to believe that the screening of mathematics achievement can be used to provide early predictors and support for interventions, before children fall seriously behind in school (Gersten, Jordan, & Flojo, 2005). In the area of reading, which has been studied more thoroughly than mathematics, reliable early screening measures with strong predictive validity have led to the development of effective support programs in kindergarten and first grade (Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002). Intermediate measures most closely allied with actual reading (e.g., knowledge of letter sounds) are more predictive of reading achievement than are more general phonological or perceptual measures (Schatschneider, Fletcher, Francis, Carlson, & Foorman, 2004). Similar to that for reading, the present study is concerned with screening key number competencies children acquire before first grade, which can serve as a ladder for learning mathematics in school.

1.1. Number sense

Number sense that is relevant to learning mathematics takes root early in life, well before children enter school. Primary, or preverbal, number sense appears to develop without or with little verbal input or instruction, and it is present in infancy (Dehaene, 1997). The development of number sense begins with precise representation of small numbers, whereas large quantities are initially captured through approximate representations (Feigenson & Carey, 2003).

It has been argued that these primary abilities are the basis for developing secondary symbolic — or verbal — number competencies (Feigenson, Dehaene, & Spelke, 2004). When children learn the verbal count list and understand cardinal values for numbers, they learn to represent larger numbers exactly and see that each number has a unique successor (Le Corre & Carey, 2007; Sarnecka & Carey, 2008). Symbolic number sense is highly dependent on the input a child receives (Clements & Sarama, 2007) and thus is secondary to primary preverbal number sense but intermediate to the conventional mathematics that is taught in school. Key areas include counting, number knowledge and arithmetic operations. Although the relation between nonverbal and

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verbal number competencies is not always clear, there is general agreement that early verbal number competencies are necessary for extending knowledge with small numbers to knowledge with larger numbers and for learning school-based mathematics.

Children first map number words onto small sets (i.e., sets of 3 or less) through subitization or instant recognition of a quantity (e.g., Le Corre & Carey, 2006). For larger sets, counting usually is needed to determine the cardinal value. During preschool and kindergarten, most children learn to enumerate sets in a stable order (e.g., 1, 2, 3, 4, 5) using one-to-one correspondence and come to realize that the last number indicates the number of items in a set (Gelman & Gallistel, 1978). Comprehension of these "how to count" principles allows children to enumerate any object or entity (e.g., heterogeneous or homogeneous) in any direction (e.g., left to right or right to left and so forth).

Counting facility extends numerical understanding in important ways (Baroody, 1987). It helps children see that numbers later in the count list have larger quantities than earlier ones (e.g., n; n + 1; (n + 1) + 1, etc.) (Sarnecka & Carey, 2008) and manipulate sets through addition and subtraction, with and without object representations (Levine, Jordan, & Huttenlocher, 1992). Learning difficulties in mathematics have been traced to weaknesses in intermediate number competencies related to counting, number comparisons, and set transformations (Geary, 1990; Mazzocco & Thompson 2005). These number abilities are highly sensitive to socioeconomic status, suggesting the importance of early input and instruction (Jordan, Huttenlocher, & Levine, 1994). For example, low-income kindergartners perform worse than their middle-income counterparts on oral number combinations and story problems involving addition and subtraction (Jordan, Levine, & Huttenlocher, 1994); they also use counting strategies less adaptively (e.g., they do not use their fingers to count on from addends; Jordan, Kaplan, Ramineni, & Locuniak, 2008).

1.2. Measuring number sense

Key number competencies can be reliably measured in kindergarten and early elementary school. Jordan and colleagues (Jordan, Kaplan, Olah, & Locuniak, 2006; Jordan, Kaplan, Locuniak, & Ramineni, 2007) developed a "core" number-sense battery for screening children in kindergarten and first grade. To assess *counting*, children are asked recite the count sequence, to count sets of different sizes, to recognize correct, incorrect (e.g., counting the first object twice), and correct but unusual counts (e.g., counting from right to left). To assess *number knowledge*, they are asked to make numerical magnitude judgments (e.g., indicating which of 2 numbers is bigger or smaller, what number comes one and two after another number). Children also are asked to perform simple addition and subtraction calculations presented in three contexts. On *nonverbal problems*, children are shown a set of chips, which is then covered. Chips are either added to or taken away from the cover. The child must indicate how many chips are under the cover after the addition or subtraction transformation. *Story problems*, which refer to objects, are orally phrased as "Sue has *m* pennies. Bill gives her *n* more pennies. How many pennies does Sue have now?" and "Sue has *m* pennies. Bill takes away *n* of her pennies. How many pennies does Sue have now?" *Number combinations* were orally phrased as "How much is *n* and *m*?" and "How much is *n* take away *m*?" Developmental studies show that children can reliably solve simple nonverbal calculations (e.g., 2 + 1) as early as three years of age, while the ability to solve comparable story problems and number combinations develops later, starting around four years of age (Levine et al., 1992).

Longitudinal assessment over multiple time points in kindergarten showed three empirically separate growth trajectories in overall number sense as well as in number subareas (Jordan et al., 2006, 2007): (a) children who started with low number competence and stayed low; (b) children who started with high number competence and remained there; and (c) those who started with low number competence but made relatively good growth. Low-income kindergartners were much more likely to be in the low-flat growth class than were middle-income kindergartners, especially with respect to addition and subtraction story problems. Children's overall performance on the number sense battery and their growth rate between kindergarten and first grade predicted overall performance and the growth rate in general mathematics achievement between first through third grades (Jordan et al., 2007; Jordan, Kaplan, Ramineni, & Locuniak, 2009) Although all subareas were significantly related to each other and to achievement outcomes, early facility with addition and subtraction number combinations was most predictive of later achievement (Jordan et al., 2007).

Although our number sense battery has good reliability and predictive validity, it has a relatively long administration time and thus may be of limited practical value to classroom teachers. To address this issue, Jordan, Glutting, and Ramineni (2008) developed a reliable but abbreviated screen (referred to as the *Number Sense Brief* or NSB) through Rasch item analyses as well as a more subjective review of issues related to item bias. Internal reliability for the screen was at least .80 in kindergarten and first grade. Although the number sense brief screen is positively correlated with mathematics achievement measures, its predictive validity has not been established.

The present study examined predictive validity of the NSB screening measure. Children were given the screening measure at the beginning of first grade and mathematics outcomes were obtained at end of both first and third grades. Outcomes included overall mathematics achievement, as well as subareas of written computation and applied problem solving. It was hypothesized that number sense proficiency may be more relevant to applied problem solving than written computation, which may be more dependent on learned algorithms. To examine the unique contribution of number sense (as measured by the number sense brief) to these later mathematics outcomes, we also added the common predictors of age, verbal and spatial abilities, and working memory skills in our analyses.

2. Method

2.1. Participants

Participants were drawn from a multi-year longitudinal investigation of children's mathematics development. They all attended the same public school district in northern Delaware. Background characteristics of children in first grade ($n = 279$) and in third grade ($n = 175$) are presented in Table 1. The first graders included children who completed all measures in first grade and the third graders were children who completed all measures in first and third grade. In the first grade sample, 55% of the children were boys, 52% were minority, and 28% came from low-income families. In the third grade sample, 54% of the children were boys, 42% were minority, and 22% came from low-income families. Income status was determined by participation

Table 1
Demographic information for participants at the end of first grade ($n = 279$) and the end of third grade ($n = 175$).

Variable	End of first grade	End of third grade
Gender		
Male	55%	54%
Female	45%	46%
Race		
Minority[a]	52%	42%
Non-minority	48%	58%
Income		
Low income	28%	22%
Middle income	72%	78%
Mean kindergarten start age (SD)	5 years–6 months (4 months)	5 years–6 months (4 months)

[a] Minority refers to African-American (29%, $n = 81$), Asian (6%, $n = 17$), and Hispanic (17%, $n = 47$) at the end of first grade; and African-American (25%, $n = 44$), Asian (6%, $n = 11$), and Hispanic (11%, $n = 19$) at the end of third grade.