Using Measures of Number Sense to Screen for Difficulties in Mathematics: Preliminary Findings

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Abstract

As recent research efforts have focused on preventing reading difficulties and enhancing the effectiveness of special education services for students with reading problems, similar efforts in mathematics have not been realized. This article describes the development and preliminary field testing of a set of measures designed to screen students in kindergarten and first grade to identify those at risk for potential mathematics difficulties. Evidence-based steps to streamline the screening process are described and plans for testing the predictive validity of the measures are outlined.

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Persistent evidence that remediation efforts for struggling learners do not result in improved outcomes have led to a focus on prevention of learning and behavioral problems before they start (Walker, Horner, Sugai, Bullis, Sprague, Bricker, & Kaufman, 1996). This prevention approach has intensified work on the development and implementation of procedures for early identification of students at-risk for later learning difficulties in key academic areas such as literacy development (Good, Simmons, & Kame'enui, 2001; Kaminski & Good, 1992; Fletcher et al., 2002). A prevention first approach borrows heavily from a public health model in which investments are made in prevention of the number of new cases of a health problem rather than waiting for the problems to occur and following them with less than optimal treatment (Simeonsson, 1994).

Currently, federally funded research centers are examining the extent to which this model is effective when applied to the area of reading instruction (Kame'enui, Simmons, Good, & Chard, in preparation; Vaughn, Linan-Thompson, & Hickman, 2003). Although results of these studies are still emerging, preliminary findings suggest that a prevention model as conceptualized by these research efforts may be a promising approach for improving literacy outcomes for students at-risk for reading difficulties while concomitantly decreasing the number of students identified and needing special education. However, a similar approach has yet to be studied in the area of mathematics.

Compared to research on reading and reading instruction, educational research on mathematics is still in its infancy. To illustrate this point, recent meta-analyses of mathematics instructional research for students with learning disabilities or low-achieving students revealed fewer than 50 studies published over the past 25 years (Baker, Gersten, & Lee, 2002; Gersten, Chard, Baker, & Lee, 2002). In contrast, a report by the National Reading Panel (2000) based on a meta-analysis of reading instruction included many hundreds of studies. Despite the relative dearth of research on mathematics instruction and learning, the importance of early mathematical development cannot be underestimated (National Research Council (NRC), 2001). There is increasing support that, like reading, mathematics proficiency is represented by a combination of important knowledge and skills, including conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive mathematical disposition (NRC, 2001).

In the primary grades, students begin to develop a wide range of knowledge in mathematics including concepts and vocabulary (e.g., more than/less than, equal), time, simple measurement, two- and three-dimensional figures, directionality, and basic operations. Despite the relatively limited knowledge base on mathematics, some research has demonstrated that students in the primary grades who demonstrate later difficulties with mathematics may, in particular, lack a strong sense of number compared to their typically developing peers (Geary, Bow-Thomas, & Yao, 1992). Number sense "refers to a child's fluidity and flexibility with numbers, the sense of what numbers mean, and an ability to perform mental mathematics and to look at the world and make comparisons" (Gersten & Chard, 1999, p. 19). Early mathematical skills that have been associated with number sense in young children include, for example, rote counting, object counting, sequencing numbers, determining which of two numbers is larger, identifying a missing number in a sequence, determining which of two numbers is closer to a third number, and counting on from a given number (Griffin, 1998; Gersten & Chard, 1999; NRC, 2001; Siegler, 1991).

Over the past 10-15 years, early reading research has demonstrated the significance of phonological awareness as a necessary precursor to the development of independent reading. The development of number sense may play an analogous role in mathematical learning (Gersten & Chard, 1999). Preliminary evidence from intervention studies that focus on number knowledge instruction (Griffin, Case, & Siegler, 1994) supports this assertion.

In preliminary research, we studied the predictive validity of number knowledge assessed in Kindergarten on students' mathematics achievement in grade 1 (Baker, Gersten, Katz, Chard, & Clarke, 2002). This predictive validation study utilized a non-experimental approach in which students' math skills were assessed once at the end of kindergarten and again at the end of first grade. Results have shown moderately strong correlations (ranging from .52 to .73) between a brief kindergarten screening measure, the *Number Knowledge Test* (Okamato & Case, 1996) and a first grade standardized measure of math achievement, the SAT-9. This finding indicates a promising direction for efficient and early identification of students who might require intervention to prevent the diagnosis of learning disabilities in the area of mathematics.

Clearly, there exists a need to improve the efficacy of general and special education by shifting focus from remediation to prevention and to better align mathematics assessment and instruction for students at-risk for mathematical difficulties. Fuchs and Fuchs (2001) have argued that prevention of mathematics difficulties necessitates a model similar to those being tested for preventing reading difficulties. In order to put a prevention system in place, we contend this will require a focus on two specific areas of research and development: (a) improvement of general education instruction in mathematics, and (b) an approach to assessment that identifies learners who are likely to struggle with mathematics difficulties in later grades and will allow teachers to monitor individual students' progress over time. Unfortunately, diagnostic measures to identify specific difficulties or disabilities in mathematics do not exist (Geary, 2004). Moreover, because mathematics disabilities are often defined in terms of students' efforts to retrieve and apply basic math facts and operation, efforts to develop measures of students' progress in mathematics have focused entirely on basic number facts, computation, and problem solving.

To address the need for an early mathematics screening instrument, we teamed with a local school district to field test a set of early mathematics measures designed to identify students who are likely to experience difficulties in later mathematics learning. The purpose of this article is to describe the field-testing results of these measures. Specifically, we examined the efficacy of our potential screening measures when compared to a validated outcome measure, the Number Knowledge Test (Okamoto & Case, 1996). The Number Knowledge Test was used in our previous work (Baker et al., 2002) and was found to be highly correlated with a published measure of mathematics achievement (i.e., *Stanford Achievement Test-Ninth Edition [SAT-9]* (Harcourt Brace Educational Measurement, 1996) in both kindergarten and first grade samples.

Method

Participants

Participants in this study were 436 kindergarten and 483 first-grade students in seven schools in a medium size school district of 5,500 students located in the Pacific Northwest. We assessed all of the students who were in the classrooms of these schools and report findings for those students who were in class at the fall, winter, and spring assessments (n = 168 in kindergarten and n = 207 in Grade 1). Across the seven schools, the percent of students who qualified for free and reduced lunch ranged from 27% to 69%. Thirteen percent of the students in the district were minorities and approximately 4% were English language learners. In kindergarten and first grade, 4% and 12.6% of students were on IEPs.

Measures

Participants were administered a set of experimental measures and one criterion measure over the course of the study (i.e., from the Fall 2002 to Spring 2003). All of the experimental measures were administered in the fall. Based on fall performance, a subset of these measures was administered again in the winter and spring. A description of the measures follows.

Experimental Screening Measures

The experimental measures used in this study were based on two research literatures, number sense and curriculum-based measurement. Our goal was to select measures of proficiency in early number skills and knowledge that were important in the development of subsequent mathematics learning knowledge (e.g., counting). Early proficiency with number knowledge has been identified as an important precursor to later mathematics success (Gelman & Gallisten, 1978; Gelman & Meck, 1983; Gersten & Chard, 1999; Griffin & Case, 1997). Geary (2004) provides a detailed description of the conceptual development of "number" in young children. Our thinking about the development of potential screening measures was also influenced by principles of curriculum based measurement (Deno, 1989), which has been studied extensively and validated primarily in the area of reading, where oral reading fluency has been found to be a consistent and excellent measure of overall reading proficiency (Shinn et al., 1992).

Clarke and Shinn (in press) assessed the psychometric properties of a set of curriculum based mathematics measures in a small-scale validation study. To build an assessment tool that would effectively screen students for mathematics difficulties, we combined the Clarke and Shinn measures with a set of other measures related primarily to the concept of number sense including counting, counting on from an identified number, count bys, and number writing (Geary, 2004).

Counting Measures

Count to 20 (C-20). The C-20 measures required participants to orally count to 20 starting with 1. No student materials were used. An examiner recorded participant responses by following along on a scoring sheet. Numbers that were correctly counted in sequence were scored as correct. Numbers that were not correctly counted in sequence were scored as incorrect. Participants were allowed to continue counting to 20 even when errors occurred in the sequence.

Count From 3 and 6 (CF3; CF6). The Counting From Measures required students to count starting at a given number with a maximum of 5 correct. For example, the participant orally counted starting at 6 for 5 numbers (i.e., to 11). Students were stopped once they reached the fifth correct number.

Count Bys 2, 5, and 10 (CB2: CB5: CB10). The Count By measures required participants to count by a given number. For example, count by twos required the student to count two, four, six . . . with a maximum correct of 10 count bys (e.g. to 20 by twos).

Number Identification Measure 1 –20 (Clarke & Shinn, in press)

The Number Identification-20 measure required participants to identify orally numbers between 0 and 20 when presented with a set of printed number symbols. Participants were given a sheet of randomly selected numbers formatted in an 8 by 7 grid. Numbers that were correctly identified were counted as correct. Numbers that were not correctly identified or skipped were counted as incorrect. If a participant struggled or hesitated to correctly identify a number for 3 seconds, they were instructed to “try the next one.” Participant performance was reported as the number of numbers correctly identified in 1 minute. The test-retest reliability of the Number Identication-20 measure ranged from .76 to .99 and concurrent and predictive validities ranged from .60 to .72 (Clarke & Shinn, in press). A variation of the Number Identification-20 measure, administered to kindergarten students, included numbers between 1 and 10 (Number Identification-10).

Number Writing (NW)

Participants were orally given a number and required to write the corresponding number symbol. All students were given the numbers 1 to 20 in random order and then given 5 more random numbers from 20 to 100.

Quantity Discrimination Measure Verbal 1-20 (Clarke & Shinn, in press)

The Quantity Discrimination-V-20 measure required students to name the larger of two visually presented numbers. Students were given a sheet of paper with a grid of individual boxes. Each box included two randomly sampled numbers from 1 to 20. Boxes in which the student correctly identified the larger number were counted as correct. Boxes in which the student named the smaller number, named any number other than the bigger number, or did not state a number were counted as incorrect. If a student stopped, struggled, or hesitated for 3 seconds, the student was instructed to "try the next one." Student performance was reported as the number of correctly identified larger numbers in 1 minute. The Quantity Discrimination -V-20 measure demonstrated test-retest reliability that ranged from .85 to .99 and concurrent and predictive validity coefficients that ranged from .70 to .80 (Clarke & Shinn, in press).

In the fall, students were allowed to either point or respond verbally (Quantity Discrimination-V/P) to the larger number in the comparison. In Winter, the mode of response (i.e., verbal or pointing (Quantity Discrimination-V/P) was tested experimentally to determine whether there was any benefit to allowing students to point rather than verbalize their response. Similar to the Number Identification measure, each of the different response modes for quantity discrimination was also tested with a restricted range of numbers from 1 to 10 for kindergarten students (Quantity Discrimination-10).

Missing Number Measure Blank Varied 1-20 (Clarke & Shinn, in press)

The Missing Number measure required the student to name the missing number from a string of numbers between 0 and 20. Students were given a sheet with 21 boxes on it. In the boxes were strings of three numbers with either the first, middle, or last number of the string missing. The student was instructed to orally state the number that was missing. Numbers missing that were correctly identified were scored as correct. Numbers missing that were not correctly identified or skipped were scored as incorrect. If a student struggled or hesitated to correctly identify a number missing for 3 seconds, they were provided the number by the examiner and instructed to "try the next one." Subject performance was reported as the number of missing numbers correctly identified in 1 minute. The Missing Number-BV-20 measure demonstrated test-retest reliability coefficients that ranged from .78 to .98 and concurrent and predictive validity coefficients that ranged from .67 to .78. Variations of the Missing Number measure included a measure in which the missing blank was always in the last position of the number string (Missing Number-BE) and a measure in which the range of numbers used was between 1 and 10 (Missing Number-BV-10).

Criterion Measure

To determine the degree to which the experimental measures accurately identify early mathematics difficulties, we selected a technically adequate criterion measure of early number sense. This measure is described below.

Number Knowledge Test (Okamoto & Case, 1996)

The Number Knowledge Test (Okamoto & Case, 1996) has been used to chart children's developmental profiles of numerical competency (Okamoto & Case, 1996) and to study the effect of math instruction on kindergarteners from low SES families (Griffin, 1998). Administered individually, this measure allows the tester to understand the "depth of understanding of numbers" (Griffin, 1998, p. 1) that a student has developed related to a particular concept.

The Number Knowledge Test was used to assess students' conceptual and procedural knowledge of numbers. Students answered number knowledge questions at increasing levels of difficulty. The first level consisted of 4 items, and began by asking the students to count 5 chips. The next two levels each consisted of 9 items, some with two parts. The student was required to answer both parts correctly in order to earn credit for each two-part item. The final and most difficult item consisted of "How much is 47 take away 21?" The interview nature of the Number Knowledge Test allowed the tester to probe students' knowledge networks to determine the level of their understanding on each concept. Its informal nature was ideal for 5 and 6 year-olds. Appropriate ceilings were established and depending on the performance of the student, the measure was administered in 4 to 6 minutes. Each correct item received a score of 1 and the total score consisted of the sum of all completed levels.

Data Collection

Data were collected three times during 2002-2003 academic year in September (fall), January (winter), and May (spring), with approximately 16 weeks between data collection periods. The data collection schedule is displayed in Figure 1.

Examiners with a background in early childhood assessment were trained to administer and score the experimental and criterion measures. The training session consisted of instruction on administering the measures according to standardized directions and following standard protocols for scoring the measures. Data collectors were observed administering and scoring each measure and appropriate feedback was provided. Feedback included what to do when students failed to supply an answer (i.e., wait 3 seconds and then ask the student to move to the next stimulus.) or when students skipped items (i.e., mark them as incorrect.). Follow-up trainings were conducted prior to each data collection period.

Preliminary Findings

Our goal was to evaluate the effectiveness of a set of early mathematics measures that might be administered in the fall of kindergarten and first grade to screen students for potential mathematics difficulties. As part of this screening battery, we wanted measures that were relatively quick to administer, showed potential for administration at both kindergarten and first grade, and that demonstrated the potential to assess student growth over the course of the year.

The first level of analysis was to calculate the correlations between our set of 10 experimental measures administered in the fall and the Number Knowledge Test administered in the fall and in the spring. In Table 1, we present the correlations for the kindergarten sample and in Table 2 we present the correlations for the first grade sample. After the fall administration, we set a correlation criterion of .50 or greater to continue to administer the predictor measures in the winter and spring. Our reasoning was that measures that correlated below .50 with the criterion measure would not prove to be useful measures in a screening battery.

Using this standard, all of the counting measures were excluded except Count by 10. In examining more closely the Count by 10 measure administered to kindergarten students in the fall, we found that over 75% of the sample scored 0. This floor effect greatly limited its potential as a screening measure so the Count by 10 measure was dropped from the battery of measures administered in the winter and spring. We also dropped the Number Writing measure because of difficulties we had accurately scoring the measure and feedback we received from teachers desiring measures that required an oral response.

The same analysis was completed with first grade students. The correlations between our ten experimental measures administered in the fall and the Number Knowledge Test administered in the fall and spring are presented in Table 2. The first three counting measures show very low correlations with the criterion. All of the count by measures are also below the .50 correlation target. Quantity Discrimination was also below the .50 target but was retained for winter and spring administration, because it was retained in the kindergarten battery and also because the distribution of the measure demonstrated the best ability of all the measures to spread students apart, a quality that is desirable in a screening battery.

Across both grades the retained measures were Number Identification, Quantity Discrimination, and Missing Number. Table 3 presents the descriptive statistics for these measures as well as for the Number Knowledge Test.

There are a number of notable patterns in Table 3 that are helpful to keep in mind in thinking about properties of a kindergarten/grade 1 (k/1) screening measure. First, as would be expected, first grade students scored higher on each measure than the kindergarten students. In each grade and across each measure there was an increase in performance from fall to winter to spring. Further evidence of this school-based performance factor is that performance in the spring of kindergarten is higher on each measure than is performance in the fall of first grade. Since these are cross-sectional data, it is not possible to state that for specific students there was a decrease in performance from spring of kindergarten to the fall of first grade, but it plausible to conclude that the summer off from school may have an adverse effect on performance on these measures. In other words, there is evidence that the measures are sensitive to school effects.

A second interesting pattern is that only Number Identification showed substantial growth from fall to spring. This change factor relates to a measures ability to index the progress students make over time. Measures where there is more change from one time point to another have more potential to effectively measure student progress because there is more room to identify change in performance over time. Quantity Discrimination and Missing Number show less change from fall to spring and therefore may not be as sensitive to the actual learning that occurs within students over time. In addition, it is interesting to note that the magnitude of the change differences is similar in kindergarten and first grade across the three measures from fall to winter to spring.

To further determine how well our set of potential screening measures, administered in the fall, were able to account for variance on the Number Knowledge Test administered in the spring, we conducted a linear multiple regression analysis on the kindergarten and first grade data. In both samples, the three predictor measures entered into the regression were Missing Number, Number Identification, and Quantity Discrimination. The criterion measure was performance on the Number Knowledge Test administered in the spring. In kindergarten, a model with two predictor measures, Missing Number and Quantity Discrimination, was statistically significant ($F = 63.0$, df $(2, 165)$, $R = .66$, $p < .01$). In light of the fact this is a kindergarten sample, and the predictor measures were administered very early in the school year, we felt the amount of variance accounted for was substantial.

With the grade 1 sample, the combination of predictor measures that accounted for largest amount of variance on the Number Knowledge Test in the spring was a set that included all three measures. Together, Missing Number, Number Identification, and Quantity Discrimination were statistically significant, meaning that all three measures accounted for significant and unique variance in the Number Knowledge Test ($F = 59.2$, $df (3, 203)$, $R = .683$, $p < .01$). As with the kindergarten sample, we felt the amount of variance accounted for by these relatively brief measures was substantial.

Discussion

In light of an expanding research base detailing the difficulty in remediating achievement gaps in reading (Torgesen, 2002; Vaughn et al., 2003), fundamental changes in the teaching and assessment of reading have occurred. Educational researchers, program developers, and teachers have renewed efforts to focus on providing early intervention reading services for students who may be at-risk for later reading failure. A prerequisite to the provision of early literacy instruction was a corresponding assessment system that could both identify those students most at-risk for reading difficulty and monitor their growth toward critical early literacy outcomes predictive of later reading success. While such systems have been developed in reading, similar assessment systems have not been developed in mathematics.

A primary purpose of the research described in this paper was to develop a measure or set of measures to be used in screening kindergarten and first grade students who might be at-risk for later difficulties in mathematics. A number of different types of measures were explored. After preliminary analysis in the fall, a set of potential measures emerged. Each of these measures was a short duration fluency based measure designed to meet a number of critical features (Fuchs & Fuchs, 1999) and to function as both an indicator of overall early math performance and a tool to monitor growth over time. The measures, Number Identification, Quantity Discrimination, and Missing Number (collectively Early Numeracy Curriculum-Based Measurement (EN-CBM)) had previously been researched with first grade students only (Clarke & Shinn, in press).

Clarke and Shinn (in press) offered evidence of the reliability (alternate form, test-retest, inter-rater) and validity (concurrent and predictive) of the EN-CBM measures with first grade students. Although reliability data were not collected, the results from the present study replicate the findings of the Clarke and Shinn study with first graders and provide preliminary evidence of predictive and concurrent validity with kindergarten students. In addition, preliminary evidence indicates that each measure demonstrated varying capacity to index growth over the duration of the school year. For example, Number Identification scores increased by 42.1 and 28.1 for kindergarten and first grade students, respectively, from fall to spring. This finding replicates and expands the findings of Clarke and Shinn (in press).

While the current study and previous work offer a starting point, further questions remain to be answered. Foremost among these questions is the need to replicate reliability findings with first grade students and collect initial reliability data with kindergarten students. From a validity standpoint, future research should focus on examining predictive validity across multiple school years. Our ongoing program of research will allow us to examine these questions by conducting follow-up data collection with kindergarten and first grade students as they advance through the early elementary grades. Evidence that the *EN-CBM* measures predict later achievement on high stakes outcomes in later grades (e.g., state benchmark tests) would offer a compelling reason for schools to use *EN-CBM* measures to identify at-risk students and provide them with intensive intervention services. While each measure can be examined individually, analysis utilizing multiple regression would provide insight into the best combinations of measures that allow accurate and meaningful predictions regarding a student's at-risk status.

Determining which combination of measures "work best" requires not only statistical analysis but consideration of other factors as well. For example, while multiple regression showed statistical significance in predicting spring Number Knowledge Test scores from Quantity Discrimination and Missing Number for kindergarten students in the fall, the role of Number Identification should not be discounted without additional evidence. Number Identification demonstrated the greatest growth over time and thus its value as a tool to monitor progress should be taken into consideration when designing a measurement net for early mathematics. In addition, future decisions regarding the suitability of each measure will need to consider reliability, validity, ability to identify students at risk for further difficulties, and ability to monitor progress.

The multiple factors that must be considered when selecting and evaluating early math measures demonstrates the complexity of early math research programs. While the research program described in this paper is in its infancy, the potential applications of developing a comprehensive assessment system for early mathematics to make valid and reliable screening and progress monitoring decisions offers a number of exciting possibilities. Foremost amongst these possibilities is the opportunity to increase the likelihood that all children will become successful with mathematics.

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Table 1

Correlations between Measures of Kindergarten Student Performance on Potential Screening Measures and the Number Knowledge Test Administered in the Fall and Spring

	Number Knowledge Test (Fall)	Number Knowledge Test (Spring)
Count to 20	.41	.38
Count from 6	.49	.39
Count from 3	.48	.40
Count by 10s	.50	.55
Count by 5s	.48	.53
Count by 2s	.45	.49
Number Writing	.63	.57
Number Identification	.65	.58
Quantity Discrimination	.55	.50
Missing Number	.69	.64

Table 2

Correlations between Measures of First Grade Student Performance on Potential Screening Measures and the Number Knowledge Test Administered in the Fall and Spring

	Number Knowledge Test (Fall)	Number Knowledge Test (Spring)
Count to 20	.12	.17
Count from 6	.18	.19
Count from 3	.07	.13
Count by 10s	.40	.40
Count by 5s	.48	.45
Count by 2s	.42	.43
Number Writing	.46	.54
Number Identification	.56	.58
Quantity Discrimination	.45	.53
Missing Number	.61	.61

Table 3

Means and Standard Deviations for Kindergartners and First Graders Fall, Winter, and Spring Performance on Key Predictor Measures.

Variable	Fall M (SD)	Winter M (SD)	Spring M (SD)
Kindergarten			
Number Identification	14.0 (13.8)	44.8 (18.1)	56.1 (17.8)
Quantity Discrimination	14.6 (7.2)	19.6 (12.0)	23.4 (10.9)
Missing Number	3.2 (4.2)	9.6 (7.1)	13.6 (6.7)
Number Knowledge Test	9.9 (4.6)	--	14.8 (5.4)
First Grade			
Number Identification	34.0 (15.8)	52.7 (17.2)	62.1 (16.3)
Quantity Discrimination	23.4 (7.2)	30.2 (9.3)	36.8 (9.0)
Missing Number	9.2 (5.7)	16.8 (6.2)	20.4 (6.2)
Number Knowledge Test	15.4 (5.1)	--	22.4 (5.9)

Figure Caption

Figure 1. Data collection schedule.