# PREVENTING EARLY MATHEMATICS DIFFICULTIES: THE FEASIBILITY OF A RIGOROUS KINDERGARTEN MATHEMATICS CURRICULUM

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> Abstract. Concern about poor mathematics achievement in U.S. schools has increased in recent years. In part, poor achievement may be attributed to a lack of attention to early instruction and missed opportunities to build on young children's early understanding of mathematics. This study examined the development and feasibility testing of a kindergarten mathematics curriculum designed to focus on the development of early number sense, geometry, measurement, and mathematics vocabulary. A mixed-model analysis of covariance, using pretest score as a covariate, was used to determine the effect of the experimental curriculum on student achievement on a standardized measure of early mathematics. Achievement results as well as implementation fidelity and teacher satisfaction suggest that further empirical research on the efficacy of the curriculum is warranted.

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The advancement and perfection of mathematics are ultimately connected with the prosperity of the state.

-Napoleon Bonaparte

Mathematics achievement is clearly important to a productive society. This long-held belief, along with recent attention to accountability and high standards, has led to serious concern about the state of mathematics education in the United States. The relatively low levels of mathematics performance of American students compared to national standards as well as in students around the world (National Research Council [NRC], 2001) have stimulated calls for a significant overhaul of mathematics education (e.g., Klein et al., 2005). Persistent problems in mathematics achievement are particularly troubling, given that the achievement gap faced by students from low-income (SES) and minority backgrounds as well as students with disabilities is significant and represents a growing number of students in public school districts (National Assessment of Educational Progress [NAEP], 2005). On the eve of the release of the National Mathematics Panel report, concern about student achievement in mathematics and an increased recognition that mathematics skill will play a significant role in life opportunities and outcomes in our society highlight the need for "[A]ll young Americans ... to think mathematically, and ... think mathematically to learn" (NRC, 2001, p. 16).

The problem of flagging achievement in mathematics in the United States may be attributed to any number of key issues that have been thoroughly discussed in the literature, including poorly prepared teachers (Hill & Ball, 2004; Ma, 1999); low expectations and poorly conceived standards (Chard & Kame'enui, 1995; Romberg & Kaput, 1999); insufficient and traditional instruction (Battista, 1999; Geist, 2000; McKnight & Schmidt, 1989); and mathematics anxiety (Furner & Berman, 2003).

Another contributor to later mathematics difficulties may simply be a missed opportunity to develop young children's mathematical understanding early. Research in developmental psychology indicates that infants demonstrate early skills in subitizing, recognizing when the number of objects or sounds changes after being habituated to a first number (Wynn, 1990, 1992). Moreover, Xu and Spelke (2000) have demonstrated that infants can perceive quantity differences in large arrays. Instruction in mathematics such as that offered to students in pre-K and kindergarten classrooms should be designed to take advantage of these already emerging skills (Clements, 2004). However, there is little empirical evidence in the research literature on instructional programs designed to teach students early number sense and to develop it more formally into early arithmetic skills in the elementary grades.

One potential approach to improving math achievement is the delivery of effective core instruction to all students in the early primary grades to lay a sound foundation for mathematical understanding and prevent early difficulties in mathematics (Clarke, Baker, & Chard, 2007). Preventing academic difficulties through focused early instruction is garnering increased attention in both general education and special education circles (Fuson, Smith, & LoCicero, 1997; Griffin, 2004). Consistent findings illustrate that remediating academic problems once they have emerged becomes increasingly difficult the longer the problems remain unresolved and content expectations grow in later grades. Fortunately, recent efforts have moved to research focused on identifying critical variables that predict which students may be at risk for later academic difficulties (Chard et al., 2005; Clarke & Shinn, 2004) and on preventing these difficulties before they become persistent problems (Fuchs et al., 2005).

Traditional mathematics instruction in early primary classrooms frequently consists of activities guided in part by students' interests and may be described as episodic rather than systematic. Popular instructional programs provide teachers with daily activities that build on students' knowledge of their environment, but are often not linked to a strong, logical sequence of instruction. In addition, many of these programs have emphasized authentic childhood activities that may or may not result in students' mastery of key concepts and skills. While intended to make mathematics more meaningful for children, these authentic activities ignored the importance of skill development to conceptual understanding (Wu, 1999).

We set out to develop a mathematics instructional program to support early mathematics development for all students in kindergarten, the Early Learning in Mathematics (ELM) program. A detailed description of the program and its conceptual foundation follows.

#### Early Learning in Mathematics (ELM) Program

The ELM program was designed to specifically enhance students' number sense. Number sense is an emerging construct (Dehaene, 1997) that refers broadly to a child's fluidity and flexibility in using and manipulating numbers, an almost intuitive sense of what numbers mean, and an ability to perform mental mathematics and look at the world and make what, in essence, boils down to quantitative comparisons without difficulty (Berch, 1998; Gersten & Chard, 1999).

While children may be born with a predisposition for making quantitative distinctions, an inability to develop a refined understanding of number has been implicated as a key predictor of later mathematics difficulties. Often, those who teach mathematics to young children, as well as those who develop curricula for teaching numbers and basic arithmetic concepts to kindergartners, fail to fully take into account that children develop, or fail to develop, number sense.

Some children acquire this conceptual structure informally. That is, they acquire number sense over time without intense formal instruction. These children acquire number sense before they begin kindergarten, either in preschool or familial settings that provide multiple and ongoing opportunities for developing quantitative thinking and analysis built on their early understanding of numbers. Other children who have not had these opportunities in preschool or at home require formal explicit instruction to develop this understanding because waiting for them to learn "on their own" the way many middle-class children seem to do takes too long, and the chance that these atrisk students will fall dangerously behind their peers before they develop it is too risky (Bruer, 1997; Griffin, 1998).

Mathematics differences among children in kindergarten are dramatic, if perhaps difficult to notice, unless they are looked for specifically. For example, one child may enter school knowing that 8 is 3 bigger than 5, while a peer with less well-developed number sense may know that 8 is bigger than 5 but have no idea by how much. Some children may not know automatically that 8 is 3 bigger than 5 but have a strategy for figuring it out by using fingers or blocks. At the other extreme are children who enter kindergarten with no idea what quantities 8 or 5 represent and find the idea incomprehensible that there is a fixed amount between them that they can precisely calculate on their fingers.

Number sense not only leads to automatic use of math information taught in school, it also is a key ingredient in the ability to solve basic arithmetic problems (Griffin, Case, & Siegler, 1994). Knowing that 15 is much further away from 8 than 11 requires an instant retrieval of two number facts (11-8 and 15-8). More than 100 basic addition facts must become automatic before students can "play around with" and contemplate these types of problems. In addition, students must also have the metacognitive awareness to know which number facts are relevant.

Number sense can be facilitated by environmental circumstances, both in and out of school. For example, Griffin et al. (1994) found that entering kindergartners differed in their ability to answer questions such as, "Which number is bigger, 5 or 4?," even when they controlled for student abilities in counting and working simple addition problems in the context of visual materials. High-SES children answered the question correctly 96% of the time, compared to low SES-children who answered correctly only 18% of the time. Griffin et al. (1994) carefully documented how, on average, in welleducated middle-class homes, a good deal of informal instruction about numbers and concepts related to numbers such as "two more" or "double" takes place. By contrast, on average, significantly less of this type of instruction occurs in low-income homes.

There is some support that instruction that includes number sense activities leads to significant reductions in mathematics failure in the primary grades (Griffin, 1998; Griffin et al., 1994). Moreover, we submit that simultaneously integrating number sense activities with early measurement concepts, simple plane geometry, and related mathematical vocabulary, rather than teaching these skills sequentially as is typically done, will reduce subsequent difficulties in mathematics. For example, explicit and systematic development of number models that build on a mental number line appears to be the critical "big idea" necessary for solving addition and subtraction problems in later mathematics learning (Phillips & Crowell, 1994).

*Conceptual framework.* Three components comprise the conceptual framework for the ELM program: (a) the

use of mathematical models; (b) mathematics-related vocabulary and discourse; and (c) procedural fluency and automaticity.

Mathematical models are used to represent important math concepts that support the development and refinement of children's number sense. ELM introduces numerals in various ways, including their position on the number line. The number line is introduced with numerals 1, 2, and 3 positioned along an arrow. As additional numbers are introduced, the numerals are added to the number line. Once numbers beyond 20 are introduced, the number line may only include a limited set of numerals such as 20-29. The number line is utilized in counting, numeral identification, writing, sequencing, quantity discrimination, and number before/number after activities.

Well-constructed representations of number also allow students to solve a wide variety of addition and subtraction problems. Students will learn to represent numbers in three different ways: (a) conventional mathematical symbols (digits, addition, equal signs); (b) horizontal number lines; and (c) hundreds chart displays. The second and third are intended to foster a sense and understanding of the number line. By utilizing only three, the students can easily trace consistencies across the representation modes. When too many representational systems are utilized, some students, especially those with disabilities or learning problems, may not notice the similarities or retain sufficient understanding of them to know which is being applied after the period of initial learning. We envision introducing children to mathematical models starting with three-dimensional models (e.g., shapes, blocks, sticks,), leading to two-dimensional representations (e.g., number lines, dots), and then moving to mathematical symbols. As learners develop facility with the conceptual models, they will be taught to use the representations to solve increasingly complex problems.

The hundreds chart also organizes numbers in logical and visual patterns and is referenced during calendar time, counting, numeral identification, and quantity discrimination activities. Individual numerals 0-10 are modeled though pairing with counting objects, finger representations, tally marks, and ten frames matched to the numeric symbol. Teen numerals are introduced conceptually, combining base ten blocks and place value mats as children practice automatic recognition and identification of these difficult numerals.

In the second component of the conceptual framework, mathematics-related vocabulary and discourse, key vocabulary is identified and explicitly taught and reviewed. Lesson scripting ensures controlled teacher definitions and application. Lesson activities are designed so children are encouraged to use mathematical vocabulary with the teacher and with peers in partner activities.

Procedural fluency and automaticity, the third component, is key to helping at-risk learners master important math concepts and skills. The lesson design provides systematic practice and review within and across lessons to ensure mastery, maintenance, and generalization of early skills. Instructional delivery utilizes frequent student opportunities to respond and individual checks for student mastery at the end of each activity. The Math Practice at the end of each lesson provides another opportunity for students to practice independently and with the teacher to check for student understanding.

Content and organization of the ELM program. ELM includes one hundred lessons divided into four quarters. Each 30-minute lesson incorporates multiple activities across four strands: numbers and operations, geometry, measurement, and vocabulary. Rather than a single skill being the focus of a lesson, four to five activities are worked on across the four strands. Familiar skills are reviewed, and new concepts and skills are introduced. A lesson may start with counting along a number line, ordering the numerals, and identifying numerals with finger representations. A new geometric shape or patterning activity may be introduced, followed by the Math Practice, a worksheet that reinforces lesson concepts and skills and includes a "Note Home" to let families know the math concepts and skills that students are working on and how they can extend practice in home-based activities.

Problem-solving activities are the focus of every fifth lesson. These whole-class and/or partner activities integrate multiple math concepts and require children to discuss and use the math-related vocabulary in application contexts. For example, an early problem-solving activity focuses on geometric shapes and vocabulary words related to various attributes of color and size. Children each select a shape and then discuss with partners how their shape is the "same" as and/or "different" from their partner's. Children then identify possible ways to group the shapes and make different sorts.

In later lessons, children play a "more or less" partner game with each child selecting a number card and determining if their number is more than or less than their partner's. The children color in a box on the "more" or "less" side of a chart and then make observations and comparisons of the results (which player had more, how many "more" turns did each partner have, etc.).

Daily calendar lessons for each month teach, reinforce, and apply mathematics concepts and skills in the context of typical "morning circle" time. Students learn the days of the week, months of the year, and seasons. They identify numbers and patterns on the calendar, and note holidays and birthdays. Students count school days by making tally marks, counting the tallies by fives and writing the number of school days. They also track the days by adding straws to place value cups and bundling sets of 10 to move to the tens cup. The hundredth-day celebration includes bundling the 10 bundled sets to move to the hundreds cup.

The scope and sequence of the curriculum exposes children to numbers through 100 with the goal of mastering 1-30. Common geometric shapes and their attributes are taught along with measurement concepts of time (hour, minute, second), telling time to the hour, measurement with non-standard units and inches, and money identification and counting with pennies, nickels, and dimes. In numbers and operations, children learn to make magnitude comparisons (numbers that are more than or less than), add 1 to a number, and solve simple additional and subtraction story problems.

## **Purpose of Study**

The present study examined the feasibility of using the ELM program in classroom practice. We used Clements' (2007) framework for research on curricula to identify three aspects of feasibility that we thought would be essential for determining whether to pursue further development and refinement of the program. These aspects include (a) the program's general effect on student learning, (b) the usability of the program, and (c) teachers' overall satisfaction with the program. Our research was guided by the following feasibility questions:

- 1. Did students receiving instruction in the ELM program demonstrate improved achievement on a standardized measure of mathematics when compared to students receiving mathematics instruction in comparison classrooms? Was there differential impact for high versus low performers in math?
- 2. Did teachers use the ELM program as intended?
- 3. Were teachers satisfied with the curriculum? Would they continue to use the curriculum beyond their formal obligations related to project completion?

#### **METHODS**

#### Participant Schools and Students

All kindergarten students in 14 elementary schools participated in the study. Schools were located in a medium-sized school district of approximately 11,000 students in the Pacific Northwest. In Year 1, 5 schools implemented the initial version of the curriculum while 4 schools served as comparison schools. During Year 1, the curriculum was revised during implementation and

then again extensively at the end of the school year. based on teacher feedback and student data in experimental and comparison schools. In Year 2, all Year 1 schools implemented the revised curriculum, and 5 new schools served as comparison schools. Data analysis was conducted on the Year 2 data only, data collected on the implementation of the revised curriculum. Treatment and comparison schools were comparable on important demographic variables and on pretest performance on the Stanford Early School Achievement Test-Fourth Edition (SESAT-2; Harcourt Brace Educational Measurement, 1996). In the Year 2 analysis, participants were 254 kindergarten students. The percent of students on free and reduced-cost lunch was 52%. Fourteen percent of students were minorities, and approximately 6% were English language learners. In the hierarchical analysis, students were nested within classrooms, and classrooms were nested within schools.

## Measures of Impact and Feasibility

Stanford Early School Achievement Test-Fourth Edition [SESAT-2] (Harcourt Brace Educational Measurement, 1996). The impact of the ELM curriculum was measured by student performance on the Stanford Early School Achievement Test-Fourth Edition (SESAT-2; Harcourt Brace Educational Measurement, 1996), which was administered at pretest and posttest to all students in intervention and comparison schools. The SESAT-2, the kindergarten version of the SAT-9, has been reported to align well with the objectives of curricula that stress development of number sense and a conceptual understanding of arithmetic concepts. The SESAT-2 is a standardized achievement test with adequate and well-reported estimates of validity (r =.64) and reliability (r = .88). The kindergarten measure comprises one subtest that includes a range of skills. Coverage areas include vocabulary such as more, less, and most; counting; dividing a whole into parts; sequencing; and single-digit addition and subtraction. SESAT standard scores were used in the analyses.

*Implementation fidelity.* Research staff observed ELM classrooms three times across the school year to determine the extent to which teachers were implementing the program as designed. Observers used checklists of lesson components and recorded the number of components implemented within each lesson. Implementation fidelity was calculated as the percentage of total components implemented.

**Teacher interviews.** To further determine feasibility and teacher satisfaction with the ELM curriculum, we interviewed teachers prior to their training in implementing the curriculum and then at again at the end of each year. The purpose of the first interview was primarily to determine participating teachers' current math instruction practices, including how often they taught math and what materials and programs they relied on during math instruction. The purpose of the interview at the end of the year was to gain insight into teachers' perspectives regarding the overall quality of the ELM curriculum, including feasibility for daily implementation, time demands, impact on student learning, and plans for further use. We concluded the end-of-year interview by having teachers rate the overall quality of the curriculum and the likelihood they would continue using the curriculum after the project.

## Training and Data Collection

Classroom teachers participated in a half-day professional development session at the beginning of the school year and prior to implementation of the ELM program. The program was then implemented by participating classroom teachers at least four days a week until they had completed all 100 lessons.

All student data were collected by examiners with a background in early childhood assessment. Data collectors were observed administering and scoring the SESAT-2. Follow-up trainings were conducted prior to each data collection period to ensure continued reliable data collection. The SESAT-2 was administered to groups of between 15 and 25 children. Interviews were conducted by one of the principal investigators and one of the co-authors of this article. Implementation fidelity was measured by research staff. On 25% of the observations two staff members conducted together, reliability estimates were above .90.

Comparison classroom teachers were encouraged to continue their "typical" approach to mathematics instruction throughout the school year. While these classrooms were not observed in this feasibility study, teachers told us that they follow Oregon's (the state in which the study took place) state standards in mathematics teaching core concepts, using manipulative materials to reinforce those concepts, employing activities that reinforce the concepts and help students build mastery of early mathematics skills. One or two teachers noted that they primarily used their own teacher-created materials with worksheets for practice.

## Analysis Methods

We assessed the impact of the curriculum using a mixed-model analysis of covariance (ANCOVA) with pretest scores as covariates for posttest outcomes. This analysis contrasted residualized outcomes scores between intervention and comparison conditions for students nested in classrooms, appropriately accounting for the dependence among students in classrooms with random classroom effects (Zucker, 1990). We fit models to our data with SAS PROC MIXED 9 (SAS Institute, 2002), using the restricted maximum likelihood method

(REML) recommended generally for multi-level models (Hox, 2002; Verbeke & Molenberghs, 2000).

In nested-design studies such as this, in which there is a relatively large number of participants but a small number of participant schools, and the school represents the unit of analysis, the tradeoff between Type I and Type II error rates represents a delicate balance. The cost of a false conclusion that intervention affects performance (Type I) is problematic. Yet, due to the high costs of conducting large efficacy studies, especially for new instructional interventions, Type II errors can also raise substantial problems, as they may obscure the value of an effective curriculum. To balance the likelihood of Type I errors with the chance of Type II errors, Cohen (1990) and Rosnow and Rosenthal (1989) recommend an adjustment to alpha, the Type I error rate. We adopted an  $\alpha$  of .10 for tests of effects on the SESAT-2.

#### RESULTS

## Student Performance: SESAT-2

Descriptive data for all participating students on the pre- and posttest administration of the SESAT-2 for ELM and comparison classrooms are presented in Table 1. To evaluate the potential impact of the mathematics curriculum, we analyzed student performance on the SESAT using the mixed-model ANCOVA. On the SESAT scores, students in Year 2 ELM classrooms exceeded the performance of students in Year 2 control classrooms by approximately 2.7 raw-score points (t = 2.18, df = 9, p = .0571) and was statistically significant with  $\alpha$  set at .10. This effect, tested on only 11 classrooms, represents a partial r of .59, or approximately 35% of the

classroom-level variance, controlling for pretest scores. In terms of total variation, individual plus classroom variation, this translates into a partial r of .13 and an effect size, d, of .26 (Cohen, 1988).

We also tested whether the intervention effect differed between low performers and high performers based on fall SESAT scores. At pretest, approximately 47% of students fell below the 25th percentile on the SESAT, so we spit the sample into two groups: students initially below the 25th percentile and students at or above the 25th percentile. We then added that variable to the mixed-model ANCOVA to test its moderator effect (Jaccard & Turrisi, 2003). The effect of the intervention did not differ for higher and lower scoring students (t = .55, df = 9, p = .5985).

#### Implementation Fidelity

The ELM curriculum was implemented in two successive years. Across both years, 6 teachers implemented the curriculum for two years and 4 teachers implemented the curriculum for one year. In the Year 2 field-testing, 9 teachers implemented the intact ELM curriculum (6 teachers implemented for the second year and 3 for the first year). Of these 9 teachers, the minimum number of lessons completed was 86 out of 100. The other teachers completed at least 95 of the 100 lessons, with a maximum of 100 and a median of 97 lessons completed. A random sample of the fidelity observations from the second year of field-testing showed that teachers completed over 80% of the activities in the lesson and that activities not completed were due to time constraints.

#### **Teacher Satisfaction**

At the conclusion of semi-structured interviews using



Levels of Use (Hall & Hord, 2001) interview procedures, teachers rated on a 1- to 5-point scale aspects of the curriculum related to (a) overall quality of the curriculum, (b) their knowledge of the curriculum, and (c) how likely they were to use the curriculum again the following year.

Across these dimensions, teachers expressed positive views of the curriculum. On overall quality, the median score was 5, and the mean score was 4.72. Knowledge of the curriculum represents teachers' perception regarding their ability to use the curriculum as intended. The median score was 5, with a mean score of 4.44. Regarding plans to use the curriculum the following year, 6 of 9 teachers rated this item a 5; the other 3 teachers rated the likelihood as 3 or 4. All 6 teachers who rated the item a 5 were implementing the curriculum for the second year, supporting our hypothesis that teachers' support for, and comfort with, the curriculum grows over multiple years of implementation.

#### DISCUSSION

There is widespread agreement on the importance of mathematical proficiency for understanding and performing sophisticated mathematics and science problems in school and across a career. At the same time, there is growing concern that U.S. schools are not addressing the challenge of preparing students adequately to engage in mathematical problem solving. While this challenge may be attributed to several factors, such as inadequate teacher preparation or inappropriate instructional foci, there is growing agreement that we may be missing the opportunity to develop early mathematical skills and knowledge that will facilitate mathematical development. Thus, several efforts to intervene with young children in mathematics have led to promising outcomes (Fuson, 2004; Griffin & Case, 1997). These efforts motivated us to design and implement the kindergarten mathematics program, Early Learning in Mathematics, presented here.

The ELM was designed to give kindergarten teachers the tools to provide effective early mathematics instruction to young children. ELM was designed around a conceptual framework that emphasized the use of mathematical models, promoted increased mathematics-related discourse, and developed procedural fluency on key mathematical skills. The content focus of ELM was on four strands of learning reflected in the NCTM's focal points: number and number operations, mathematical vocabulary, geometry, and measurement. After a half day of professional development, teachers implemented ELM for 30 minutes daily up to four days per week, with most teachers completing approximately 85 out of a total of 100 lessons. The primary objective of this study was to examine the feasibility of the ELM program for use in typical kindergarten classrooms. We approached this study from the perspective that curriculum development is a design science (Brown, 1992; Clements, 2007; Simon, 1969). From this type of science, Clements (2007) noted, two goals may be achieved, "engineering a learning process and developing local theories" (p. 37).

The present study represents our effort to engineer an instructional tool to support teachers' work with young children in mathematics and to validate, in part, a conceptual framework that is premised on the prevention of learning problems in mathematics through early, effective instruction in key knowledge and skills. In terms of feasibility, we were particularly interested in determining the usability of the program, as measured by teachers' fidelity of implementation and their overall perception of the effectiveness and usability of the materials, and to gauge the effects of the program on student learning as measured on standardized mathematics assessment. Outcomes in this combination of areas, favorable or not, would help us determine the direction of our future design research.

#### **Major Findings**

Student outcomes. We argue that the most important intended consequence of any curriculum-design study is student learning. While feasibility studies often do not go so far as to report student outcomes relative to a comparison group, we believe it is critical to do so to determine whether our design is appropriately conceived and what, if any, refinements may be necessary. Therefore, we implemented a pre-post controlgroup design with schools assigned to treatment. This design, while underpowered (with only 14 schools), allowed us to make preliminary inferences about the quality and effectiveness of the ELM program compared to more traditional kindergarten mathematics instruction.

The results on the SESAT-2 were promising and favored the classrooms in which the ELM was implemented. The ELM accounted for 35% of the variance in scores after accounting for pretest differences and resulted in a meaningful positive effect, d = .26. This finding suggested to us that the design and content of the ELM is likely to be focused on knowledge and skill areas that are aligned with the assessment and warrants further study of its efficacy.

*Fidelity of implementation.* Measuring fidelity of implementation in educational research has become increasingly important over the past 15-20 years. Reviews of research on instructional interventions reveal that, in the past, it was common simply to provide a description of the intervention being

studied and its comparison without reference to the degree to which the program was implemented as designed (Chard, Ketterlin-Geller, Baker, Doabler, & Apichatabutra, in press; Baker, Chard, Ketterlin-Geller, Apichatabutra, & Doabler, in press). Recently, however, it has become more standard to provide measures of implementation fidelity.

For the purposes of the present study, implementation fidelity served as an indicator of teachers' ability to implement the ELM program in such a way that student outcomes could be attributed to it as an independent variable. We were hoping that teachers would find the program usable and would implement it with high levels of fidelity at the major component level. But we were also aware that fidelity to instructional materials must be balanced with responsiveness to student needs and, therefore, encouraged teachers to use their professional judgment to determine when students needed further support on a concept or skill and to respond accordingly with additional models or feedback that would facilitate their learning. Teachers reported on teacher logs that they completed the majority of the 100 lessons in the ELM and were able to complete most of the activities in each lesson, depending on time. This indicates that the ELM's design is such that teachers found it relatively easy to incorporate into their school day and did not find any major obstacles to its use.

Teacher satisfaction. Results of teacher interviews suggest that overall teachers were very satisfied with the ELM. This was not a tremendous surprise to us, as part of our impetus to develop the ELM was teachers' requests for support in primary-grade mathematics. Many teachers had shared with us that they had been using the same instructional methods in mathematics for kindergarten for many years and that they were concerned that expectations for student knowledge were exceeding what they were teaching. We interpreted this to mean that while they were doing their best to help students learn about early mathematics, the standards and accountability system were raising expectations for what students learn in the early primary grades. We were particularly pleased to find that teachers who had been implementing for more than one year demonstrated an even higher regard for the program than those who were first-year implementers. We had a hunch that teachers would find the program easier to implement after they had taught it once. To achieve the elements of the conceptual design of the program involved organizing many manipulative materials as well as many discourse-intensive activities. Implementing ELM for a second year seemed to reduce teachers' concerns about organization and implementation.

#### Limitations

We report in this article the outcomes of a study of feasibility. It is not common in the research literature to find open descriptions of feasibility research as it often is not considered rigorous enough for publication. We have attempted to report candidly how we went about studying the early effects of the ELM while acknowledging that the research is formative and warrants further study.

That noted, the limitations of the study seem rather obvious. For example, we were not able to randomly assign students but rather assigned classrooms to condition. Consequently, our study was severely underpowered. We only had enough resources to complete fidelity observations three times for each teacher across the school year. Such a low frequency of observation may overestimate actual fidelity of implementation. Additionally, we did not document the activities in which comparison classrooms were engaged. It is very likely that there was a range of activities going on in those classrooms, some of which were similar to those in ELM. Participating teachers represented an experienced group of professionals who demonstrated an interest in mathematics. We suspect that they were working hard to improve their students' learning regardless of the condition to which they were assigned.

#### Implications for Future Research

Given the critical role of mathematics in a productive society, the importance of the relationship between science and curriculum development cannot be overstated. However, Clements (2007) noted that curriculum development and scientific research have typically been isolated from one another. We concur, and our intent in this article was to describe how we conducted a feasibility study of a kindergarten mathematics instructional program as a precursor to studying the efficacy of the program in a more scientific manner.

One obvious implication for future research is the need to design and implement a more formal efficacy study using an experimental design with random assignment of students to condition. This type of study would include a larger sample, thus allowing us to assess the efficacy of the instructional program on student mathematical outcomes. Additionally, our outcomes of the present feasibility study will guide us to more thoroughly assess the benefits of ELM on the development of specific skills such as math vocabulary or number operations. We plan to approach this through measures that will include more proximal measures such as curriculum-based and mathematics vocabulary measures as well as standardized assessments. Measuring skills that are taught with more proximal measures will help confirm the conceptual framework upon which ELM was designed.

It is critical that research on mathematics instructional materials result in knowledge of the materials' effects on student outcomes. However, in addition to measuring and reporting direct effects of instructional materials, it is also important to assess unintended effects, such as how the materials influence teachers' knowledge and practices (Clements, 2007). Teachers' knowledge of mathematics and mathematics pedagogy has been described as essential to children's mathematics development (Ball, Hill, & Bass, 2004). It is likely that teachers grow in their understanding of the subject matter they teach and children's learning as a result of years of classroom experience. Thus, our initial evidence suggests that teachers were more comfortable implementing ELM during their second year of implementation. This comfort seemed to be echoed in their responses to questions about their satisfaction. Efforts to develop measures of teacher knowledge may allow us to ultimately directly measure ELM's effects on teachers' mathematics and mathematics pedagogical knowledge.

In our future work, we will continue to observe teachers' classroom instruction for fidelity of implementation. Additionally, we plan to document the frequency and quality of instructional interactions in both ELM and control conditions that may serve to mediate mathematics achievement. We hypothesize that teachers' interactions with students are likely to play an important role in helping struggling students to access instruction and improve their mathematics achievement. For example, we know that some students benefit from additional examples of models and opportunities to demonstrate a skill with feedback. Other students do not need this additional reinforcement. We hope to document how teachers address these differences through their interactions with students in the classroom.

#### REFERENCES

- Baker, S. K., Chard, D. J., Ketterlin-Geller, L. R., Apichatabutra, C., & Doabler, C. (in press). The basis of evidence for self-regulated strategy development. *Exceptional Children*.
- Ball, D. L., Hill, H. C., & Bass, H. (2005, Fall). Knowing mathematics for teaching. *American Educator*, 14-46.
- Battista, M. T. (1999). The mathematical miseducation of America's youth: Ignoring research and scientific study in education. *Phi Delta Kappan, 80,* 424-433.
- Berch, D. B. (1998, April). *Mathematical cognition: From numerical thinking to mathematics education*. Conference presented by the National Institute of Child Health and Human Development, Bethesda, MD.
- Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in evaluating complex interventions in classroom settings. *The Journal of the Learning Sciences*, 2(2), 141-178.

- Bruer, J. T. (1997). Education and the brain: A bridge too far. *Educational Researcher, 26*(8), 4-16.
- Chard, D. J., Ketterlin-Geller, L. R., Baker, S. K., Doabler, C., & Apichatabutra, C. (in press). Repeated reading interventions for students with learning disabilities: Status of the evidence. *Exceptional Children*.
- Chard, D. J., & Kameenui, E. J. (1995). Mathematics instruction for students with diverse learning needs: Heeding the message of the Cheshire cat. *Focus on Learning Problems in Mathematics*, 17(2), 24-38.
- Chard, D. J., Clarke, B., Baker, S., Otterstedt, J., Braun, D., & Katz, R. (2005). Using measures of number sense to screen for difficulties in mathematics: Preliminary findings. Assessment for Effective Intervention, 30(2), 3-14.
- Clarke, B., & Shinn, M. (2004). A preliminary investigation into the identification and development of early mathematics curriculum-based measurement. *School Psychology Review*, 33(2), 234-248.
- Clarke, B., Baker, S. K., & Chard, D. J. (2007). Measuring number sense development in young children: A summary of early research. *Leadership to Math Success for All*, *5*, 1-11.
- Clements, D. H. (2004). Major themes and recommendations. In D. H. Clements & J. Sarama (Eds.), *Engaging young children in mathematics: Standards for early childhood mathematics education* (pp. 7-72). Mahwah, NJ: Erlbaum.
- Clements, D. H. (2007). Curriculum research: Toward a framework for "research-based curricula." Journal for Research in Mathematics Education, 38(1), 35-70.
- Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). New York: Academic Press.
- Cohen, J. (1990). Things I have learned (so far). American Psychologist, 45(12), 1304-1312.
- Dehaene, S. (1997). The number sense: How the mind creates mathematics. New York: Oxford University Press.
- Fuchs, L. S., Compton, D. L., Fuchs, D., Paulson, K., Bryant, J. D., & Hamlett, C. L. (2005). The prevention, identification, and cognitive determinants of math difficulty. *Journal of Educational Psychology*, 97(3), 493-513.
- Furner, J. M., & Bernan, B. T. (2003). Math anxiety: Overcoming a major obstacle to the improvement of student math performance. *Childhood Education*, 79(3), 170-174.
- Fuson, K. C. (2004). Pre-K to grade 2 goals and standards: Achieving 21st-century mastery for all. In D. H. Clements & J. Sarama (Eds.), *Engaging young children in mathematics: Standards for early childhood mathematics education* (pp. 105-148). Mahwah, NJ: Erlbaum.
- Fuson, K. C., Smith, S. T., & LoCicero, A. (1997). Supporting Latino first graders' ten-structured thinking in urban classrooms. *Journal for Research in Mathematics Education*, 28, 738-760.
- Geist, E. A. (2000). Lessons from the TIMMS videotape study. *Teaching Children Mathematics*, 7(3), 180-185.
- Gersten, R., & Chard, D. J. (1999). Number sense: Rethinking math instruction for students with learning disabilities. *The Journal of Special Education*, *33*, 18-28.
- Griffin, S. (1998) *Number worlds*. Durham, NH: Number Worlds Alliance.
- Griffin, S. (2004). Number worlds: A research-based mathematics program for young children. In D. H. Clements & J. Sarama (Eds.), *Engaging young children in mathematics: Standards for early childhood mathematics education* (pp. 325-340). Mahwah, NJ: Erlbaum.
- Griffin, S., & Case, R. (1997). Rethinking the primary school math curriculum: An approach based on cognitive science. *Issues in Education*, 31(1), 1-49.

- Griffin, S., Case, R., & Siegler, R. (1994). Rightstart: Providing the central conceptual prerequisites for first formal learning of arithmetic to students at-risk for school failure. In K. McGilly (Eds.), Classroom lessons: Integrating cognitive theory and classroom practice (pp. 24-49). Cambridge, MA: Bradford Books MIT Press.
- Hall, G. E., & Hord, S. M. (2001). *Implementing change: Patterns, principles, and potholes*. Boston: Allyn and Bacon.
- Harcourt Brace Educational Measurement. (1996). Stanford achievement test series, ninth ed. San Antonio, TX: Author.
- Hill, H. C., & Ball, D. L. (2004). Learning mathematics for teaching: Results from California's Mathematics Professional Development Institutes. *The Journal for Research in Mathematics*, 35, 330-351.
- Hox, J. J. (2002). *Multivariate analysis: Techniques and applications*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Jaccard, J., & Turrisi, R. (2003). Interaction effects in multiple regression (2nd ed.). Thousand Oaks, CA: Sage.
- Klein, D., Braams, B. J., Parker, T., Quirk, W., Schmid, W., & Wilson, W. S. (2005). *The state of state math standards*. Washington, DC: Fordham Foundation.
- Ma, L. (1999). Knowing and teaching elementary mathematics. Mahwah, NJ: Lawrence Erlbaum Associates.
- McKnight, C. C., & Schmidt, W. H. (1989). Facing facts in U.S. science and mathematics education: Where we stand, where we want to go. *Journal of Science Education and Technology*, 7(1), 57-76.
- National Assessment of Educational Progress. (2005). *The nation's report card: Mathematics 2005* (Report No. NCES-2006-453). Washington, DC: U.S. Department of Education, National Center for Education Statistics.
- National Research Council. (2001). Adding it up: Helping children learn mathematics. Washington, DC: Mathematics Learning Study Committee.

- Phillips, D., & Crowell, N. A. (Eds.), (1994). *Cultural diversity and early eduaction: Report of a workshop*. Washington, DC: National Academy Press.
- Romberg, T. A., & Kaput, J. J. (1999). Mathematics worth teaching, mathematics worth understanding. In E. Fennema & T. A. Romberg (Eds.), *Mathematics classrooms that promote understanding* (pp. 3-17). Mahwah, NJ: Erlbaum.
- Rosnow, R. L., & Rosenthal, R. (1989). Statistical procedures and the justification of knowledge in psychological science. *American Psychologist*, 44(10), 1276-1284.
- SAS Institute. (2002). SAS OnlineDoc® 9: SAS/STAT 9 user's guide, volumes 1, 2, and 3. Cary, NC: SAS Institute, Inc. Retrieved September 09, 2007, from http://v9doc.sas.com/sasdoc/
- Simon, H. A. (1969). *The sciences of the artificial*. Cambridge, MA: MIT Press.
- Verbeke, G., & Molenberghs, G. (2000). Linear mixed models for longitudinal data. New York: Springer-Verlag.
- Wu, H. (1999, Fall). Basic skills versus conceptual understanding: A bogus dichotomy in mathematics education. *American Educator*, 1-7.
- Wynn, K. (1990). Children's understanding of counting. *Cognition*, 36, 155-193.
- Wynn, K. (1992). Addition and subtraction by human infants. *Nature, 358,* 749-751.
- Xu, F., & Spelke, E. S. (2000). Large number discrimination in 6month-old infants. *Cognition*, 74, B1-B11.
- Zucker, D. M. (1990). An analysis of variance pitfall: The fixed effects analysis in a nested design. *Educational and Psychological Measurement*, 50, 731-738.

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