School Psychology Review,
2016, Volume 45, No. 3, pp. 343–361

Research Into Practice

Effects of a Core Kindergarten Mathematics Curriculum on the Mathematics Achievement of Spanish-Speaking English Learners

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Abstract. There is a dearth of research on Tier 1 instruction designed to improve the mathematics achievement of English learners. This study examined the impact

The authors declare the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Drs. Ben Clarke, Scott K. Baker, and Hank Fien are eligible to receive a portion of royalties from the University of Oregon's distribution and licensing of certain Early Learning in Mathematics-based works. Potential conflicts of interest are managed through the University of Oregon's Research Compliance Services. An independent external evaluator and coauthor of this publication completed the research analysis described in the article.

The research reported here was supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305A080699 to the Center on Teaching and Learning at the University of Oregon.

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of a core kindergarten mathematics curriculum on the mathematics achievement of Spanish-speaking English learners (SS-ELs). Secondary aims tested for differential response to the curriculum among SS-ELs as a function of (a) mathematics skills at the beginning of kindergarten, (b) the number of SS-ELs in classrooms, and (c) the frequency of mathematical discourse during core mathematics instruction. Data analyzed in the study were generated from a recent large-scale efficacy trial. Participants were 556 SS-ELs from 66 kindergarten classrooms. Results suggest SS-ELs in treatment classrooms made greater gains than SS-ELs in comparison classrooms on mathematics measures across the school year. Evidence of differential response to the curriculum among SS-ELs was not found. The importance of core mathematics instruction and implications for school psychologists are discussed.

While the societal importance of teaching for early mathematical proficiency has gained national attention (National Mathematics Advisory Panel [NMAP], 2008), mounting evidence suggests that students from a variety of subgroups struggle to meet grade-level expectations in mathematics. Among these at-risk subgroups are English learners (ELs) or children of linguistic minority groups who lack full proficiency in English and receive language assistance. ELs represent a major presence in U.S. schools, and for the past 20 years, they have been the fastest growing subgroup (Klingner & Eppolito, 2014). Recent estimates suggest that ELs comprise 10% of the U.S. student population and that 70% of this subgroup is Spanish speaking (Fry & Passel, 2009). Considering the rising presence of ELs in U.S. public schools and the alarming number being disproportionately identified for special education (Sullivan, 2011), schools and teachers face the daunting challenge of meeting the instructional needs of ELs. Recent research shows, however, that schools are struggling to support ELs in developing mathematical proficiency.

Mathematics achievement data from the 2013 National Assessment for Educational Progress (NAEP) indicate that 86% and 95% of fourth-grade and eighth-grade ELs, respectively, scored below proficient (National Center for Education Statistics [NCES], 2013). There are also strong indications that ELs do not achieve commensurate with their English-proficient peers. According to recent research, the math achievement gap between ELs and English-proficient students appears early and remains relatively stable over the years (Reardon & Galindo, 2009). Since 1996, NAEP results have shown that an educationally meaningful achievement gap exists between ELs in fourth grade and their English-proficient peers and that this gap is nearly twice as large in eighth grade (NCES, 2013).

The convincing evidence that suggests ELs experience early and persistent math difficulties comes at a time when the Common Core State Standards for Mathematics (CCSS-M; Common Core State Standards Initiative [CCSSI], 2010) have significantly raised the mathematical proficiency bar for U.S. students. The CCSS-M, relative to previous state standards, places greater demand on the development and use of academic language in math (Dingman, Teuscher, Newton, & Kasmer, 2013). Students must now use precise mathematical language and vocabulary, verbalize and justify solution methods, and critique the reasoning of others (Standards for Mathematical Practice; CCSSI, 2010). While all students face the linguistic challenges associated with learning to use the language of math in the context of the CCSS-M, these demands are compounded for ELs. They, unlike their peers who are native English speakers, face the unfortunate "double demands" (Baker et al., 2014) of having to simultane-

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ously acquire proficiency in two languages: English and mathematics (Cirillo, Richardson Bruna, & Herbel-Eisenmann, 2010; Moschkovich, 1999).

Given the likelihood that many ELs will struggle to acquire math proficiency, a major focus of educational research and practice should be on improving the quality of core math instruction delivered in general education settings. For many students, core math instruction serves as the primary source of math instruction. This is particularly true in the early elementary grades, when logistic constraints (e.g., half-day programs in kindergarten) and a primary focus on reading instruction may limit the availability of time and resources to support math achievement beyond core instruction. Core math instruction, therefore, must be effectively designed and delivered to meet the instructional needs of all students, including ELs and other students at risk for math difficulties. Evidence from recent randomized controlled trials has begun to document the utility of effective core math instruction in promoting student math achievement, preventing math difficulties, and reducing student need for highly intensive math interventions (Agodini & Harris, 2010; Chard et al., 2008; Clarke et al., 2011; Fuchs, Fuchs, & Prentice, 2004).

PLAUSIBLE SOURCES OF MATH DIFFICULTIES FOR ELS

While many factors (e.g., sociocultural, linguistic, cognitive) may contribute to the difficulties that ELs experience in acquiring math proficiency, it is important to consider how instructional factors influence and, in some cases, initiate difficulties in math. A lack of language-intensive instruction is one instructional factor that may explain why so many ELs are struggling with math and other academic areas (Cirillo et al., 2010; Lee, Quinn, & Valdés, 2013; Moschkovich, 1999). Research in the areas of reading (Baker et al., 2014; Gersten et al., 2007), social studies (Vaughn et al., 2009), and science (August et al., 2014; Lee et al., 2013) has found that the academic achievement of ELs is dependent on meaningful opportunities to engage in the use of disciplinary language. In this study, we hypothesized that this principle would also hold true for ELs in the area of math. We base this hypothesis on findings from a growing line of classroom observation research that has shown that increased student math achievement is associated with student math verbalizations (Clements, Agodini, & Harris, 2013; Doabler et al., 2015). It can be argued then that classrooms, particularly those with higher percentages of ELs, should provide structured opportunities for students to verbalize their mathematical understanding and thought processes.

An underdeveloped empirical research base in the area of effective math instruction for ELs can also be implicated as a contributing factor to the difficulties ELs face with math. While significant efforts have been made in the practice of preventing reading difficulties for ELs (Baker et al., 2014; Gersten et al., 2007), few rigorously conducted studies have investigated the impact of interventions on the math achievement of ELs. For example, Janzen (2008) conducted a synthesis of the literature from 1990 to 2007 on teaching ELs in the content areas of English, math, science, and history. Janzen classified the findings within each content area into linguistic, cognitive, sociocultural, and pedagogical subcategories. None of the 12 articles codified under the pedagogical category in math used a research methodology, such as a randomized controlled trial, quasi-experimental design, or single-case design, rigorous enough to identify and establish the causal agents linked to improved math achievement for ELs (Flay et al., 2005).

Since Janzen's (2008) review, there has been a continued lack of rigorous experimental research on math instruction for ELs. In fact, Richards-Tutor, Baker, Gersten, Baker, and Smith (2016) conducted a review of the literature base from 2000 to 2012 and found no experimental studies on math interventions with ELs. Our own review of the research from 2013 to the time of this study revealed just three math intervention studies involving ELs (i.e., Orosco, 2014; Orosco, Swanson, O'Connor, & Lussier, 2011; Shumate, Campbell-Whatley, & Lo, 2012). This paucity of research sheds light on the urgency to build the knowledge base on effective math instruction for ELs. This study sought to address this need by conducting a secondary analysis on the impact of a core (Tier 1) kindergarten curriculum on the math outcomes of Spanish-speaking English learners (SS-ELs).

EXPLICIT MATH INSTRUCTION AND ITS ROLE IN MATH PROFICIENCY FOR ELS

One instructional approach that has strong potential for supporting ELs in developing mathematical proficiency is explicit math instruction. Over the past decade, research has begun to establish a solid evidentiary basis for using explicit math instruction to teach at-risk learners (Baker, Gersten, & Lee, 2002; Bryant et al., 2011; Clarke et al., 2011; Gersten et al., 2009; NMAP, 2008; Orosco, 2014; Orosco et al., 2011). For example, in a meta-analysis of 41 studies targeting students with math difficulties, Gersten et al. (2009) found that explicit instruction had the largest impact, $g = 1.22$, 95% CI [0.78, 1.67], among seven dimensions of math instruction.

In this study, we hypothesized that a core math curriculum characterized by a systematic and explicit instructional architecture would have positive effects on the math outcomes of SS-ELs. We based this hypothesis on several factors. First, a systematic core curriculum judiciously prioritizes instruction around critical content, connects new content with students' background knowledge, selects and sequences instructional examples, and scaffolds instruction. These design features are employed to ensure high rates of student success with new and complex math concepts. Second, explicit math instruction expects teachers to overtly model and demonstrate what they want students to learn. Research from the learning sciences suggests that explicit demonstrations are a more efficient and effective way of presenting critical academic content to students compared with less explicit teaching methods, such as discovery and problem-based learning, as well as inquiry-based teaching (Mayer, 2004). A third reason explicit math instruction may benefit ELs is that it offers timely and specific academic feedback as students engage in guided and independent learning activities. A growing body of evidence indicates that providing specific, informational feedback about a student response or action improves learning and helps students understand how they performed during the process of learning (Halpern et al., 2007; Hattie & Timperley, 2007).

Fourth, explicit math instruction also systematically incorporates visual models to promote a deep understanding of key concepts and skills (Doabler et al., 2012). At-risk learners often experience difficulties understanding the relationship between math models and abstract symbols and therefore require support in making this crucial connection (Gersten et al., 2009). A fifth reason explicit math instruction may benefit ELs is that this instructional approach facilitates productive discourse around critical math content and incorporates systematic opportunities to support key vocabulary development. In this study, *productive math discourse* is operationally defined as verbalizations between students and teachers, as well as among students, around critical math concepts. Empirical studies point to the fact that for young students to learn math, they must be given deliberate opportunities to verbalize their mathematical thinking (Doabler et al., 2015; Gersten et al., 2009). Such verbalizations can help ELs build critical language skills in both English and mathematics (Baker et al., 2014).

EMPIRICAL SUPPORT FOR THE IMPLEMENTATION OF AN EXPLICIT CORE MATHEMATICS CURRICULUM

While explicit math instruction is most well known for its role in small-group interventions, we have found encouraging results when using this instructional approach in core educational settings (i.e., general education classrooms). A primary focus of this line of efficacy research has been the Early Learning in Mathematics (ELM) curriculum. ELM is a yearlong, 120-lesson core curriculum that targets kindergarten math topics identified in the CCSS-M (CCSSI, 2010). Our research team developed the ELM curriculum based on an explicit and systematic architecture to early math instruction. Under this framework, ELM incorporates validated, explicit instructional design and delivery principles (Chard et al., 2008; Clarke et al., 2011) and thus targets the instructional needs of all students, including typically achieving students, students with math difficulties, and ELs with various first languages.

Recent efficacy research has documented preliminary empirical support for ELM's capacity to (a) increase the math achievement of struggling learners (Chard et al., 2008; Clarke et al., 2011) and (b) support teachers in facilitating structured classroom discourse around critical math concepts and skills (Doabler et al., 2014). In a recent randomized controlled trial, we tested the efficacy of ELM, randomly assigning 66 kindergarten classrooms to treatment and control conditions (business as usual) (Clarke et al., 2011). The student sample included approximately 1,300 kindergarten students, including at-risk and typically achieving children. Analyses revealed statistically significant effects for students in ELM classrooms over students in control classrooms on the Test of Early Mathematics Ability–Third Edition (TEMA-3; $t = 2.41$, $p = .02$, Hedges's $g = 0.15$) and Early Numeracy Curriculum-Based Measurement (EN-CBM; $t = 1.99$, $p = .05$, $g = 0.13$). We also found that at-risk students (i.e., students who scored below the 40th percentile on the TEMA-3 at pretest) significantly outperformed their at-risk control peers on both the TEMA-3 ($t = 3.29$, $p < .01$, $g = 0.24$) and EN-CBM total score ($t = 2.54$, $p = .01$, $g = 0.22$).

More recently, Doabler et al. (2014) investigated the efficacy of the ELM curriculum in 129 kindergarten classrooms from 46 schools in Oregon and Texas. The study differed from previous investigations of ELM (Chard et al., 2008; Clarke et al., 2011) in that it had a specific focus on teacher outcomes rather than student math achievement. Doabler et al. examined whether ELM increased teachers' facilitation of high-quality instructional interactions. Findings suggested that ELM stimulated more opportunities for teachers and students to engage in high-quality mathematical discussions compared with classrooms in the control condition. Specifically, higher rates of math verbalizations by groups of students ($t = 5.09$, $p < .001$, $g = 0.91$) and individuals ($t = 3.30$, $p = .001$, $g = 0.57$) were found in ELM classrooms.

PURPOSE OF THE CURRENT STUDY AND RESEARCH QUESTIONS

A clear and compelling need exists to build a scientific knowledge base of effective instructional practices aimed at increasing the math achievement of ELs. To this end, the purpose of this study was to investigate the impact of the ELM core math curriculum on the math achievement of SS-ELs. To our knowledge, no similar research on core mathematics instruction for ELs in general, and SS-ELs in particular, has been conducted.

In addition to studying the efficacy of ELM, we tested a set of a priori student- and classroom-level predictors of differential response to the ELM curriculum (Burns, 2011). Because level of mathematical knowledge at kindergarten entry is a proxy of risk status and has been found to be one of the strongest predictors of later math achievement (Duncan et al., 2007; Morgan, Farkas, & Wu, 2009), we examined whether the effects of ELM differed by SS-ELs' initial skill performance in math. In addition, we investigated whether the extent to which SS-ELs are distributed across classrooms influenced the efficacy of ELM. Recent studies have suggested that classrooms with higher percentages of disadvantaged students, including SS-ELs, produce lower student math achievement (Isenberg et al., 2013). We also tested whether the use of mathematical language in classrooms was a predictor of differential response to ELM. As math standards increasingly emphasize the need for students to understand math concepts and demonstrate their mathematical understanding through verbal explanations of what math problems are asking and how they can be solved, this study offered an important opportunity to test the impact of an innovative approach in math with SS-ELs. It may be, for example, that by facilitation of multiple opportunities for students to verbally express their mathematical thinking and problem solving, SS-ELs will have more opportunities to understand math concepts and procedures and improve their math skills. We believe this study is the first to investigate such a hypothesis, particularly in the context of testing the impact of a core math curriculum with a strong emphasis on math discourse.

In summary, this study was guided by the following four research questions:

1. What is the effect of the ELM curriculum on the math achievement among SS-ELs?
2. Do math skills at the beginning of kindergarten, as measured by the TEMA-3, predict differential response to the ELM curriculum among SS-ELs?
3. Does the number of SS-ELs in classrooms predict differential response to the ELM curriculum among SS-ELs?
4. Does the frequency of math discourse in classrooms predict differential response to the ELM curriculum among SS-ELs?

METHOD

This study conducted a secondary analysis of data collected during a large-scale efficacy trial funded by the Institute of Education Sciences and designed to investigate the efficacy of the ELM core kindergarten curriculum (Clarke et al., 2011). The ELM efficacy trial was conducted in Oregon and Texas during the 2008–2009 and 2009–2010 school years, respectively (Clarke et al., 2011; Doabler et al., 2014). With blocking on schools, 129 kindergarten classrooms were randomly assigned to either treatment (ELM, $n = 68$) or comparison (district-approved kindergarten math instruction, $n = 61$) conditions. Thus, the ELM efficacy trial treated classrooms as the primary unit of analysis. In all, the original sample included 2,598 kindergarten students attending 129 classrooms in 46 schools. The ELM efficacy trial collected data from participating students to (a) document demographic characteristics and (b) measure gains in student math achievement from the beginning to the end of kindergarten. Classroom observations were also conducted in both conditions at fall, winter, and spring time points to measure the amount of math classroom discourse used during core math instruction.

Prior to analyzing the data, we established two inclusion criteria for what would constitute an eligible ELM efficacy trial classroom. A classroom was considered eligible if it (a) enrolled students considered as ELs whose first language was Spanish and (b) provided complete student demographic data related to students' English language status. From the original sample of 129 kindergarten classrooms, 63 classrooms were dropped because they did not include SS-ELs or because they provided incomplete EL status information. In total, our analytic sample included 66 kindergarten classrooms with 556 students considered as SS-ELs. Data analyzed in the current study included student math achievement data and observational data documented in the 66 kindergarten classrooms.

Teacher and Student Sample

The 66 classrooms (35 treatment, 31 comparison) were from 26 schools located in three school districts in Oregon and one school district in Dallas, Texas. Teachers in treatment classrooms delivered the ELM curriculum. In comparison classrooms, teachers provided district-approved kindergarten math instruction. All 66 classrooms were located in public schools, and most schools were eligible for Title 1 funding. Table 1 provides descriptive information about the classrooms and teachers by condition. Of the 66 classrooms, 52 provided a full-day kindergarten program and 14 provided a half-day program. All half-day classrooms were located in Oregon, and math instruction in all classrooms was delivered in English. The average class size for treatment and comparison classrooms was 23.0 ($SD = 5.3$) and 21.9 ($SD = 4.4$), respectively.

Table 1. Descriptive Information for Students and Classrooms by Condition

	ELM	Comparison
Student characteristics		
No. of students	328	228
Age, years, *M* (*SD*)	5.6 (0.5)	5.6 (0.5)
Male, *n* (%)	172 (52)	112 (50)
Hispanic, *n* (%)	303 (92)	211 (93)
Eligible for special education, *n* (%)	19 (6)	15 (7)
Classroom characteristics		
No. of classrooms	35	31
No. of students per class, *M* (*SD*)	23.0 (5.3)	21.9 (4.4)
No. of SS-ELs per class, *M* (*SD*)	10.2 (6.0)	8.2 (5.2)
Program structure, *n* (%)		
Full-day program	29 (83)	23 (74)
Half-day program	6 (17)	8 (26)
Rate of group responses per min, *M* (*SD*)	1.3 (0.5)	1.0 (0.7)
Rate of individual responses per min, *M* (*SD*)	0.5 (0.3)	0.5 (0.3)
Rate of group and individual responses per min, *M* (*SD*)	1.8 (0.7)	1.5 (0.8)
Rate of math language per min, *M* (*SD*)	3.2 (1.0)	2.7 (1.4)

Note. Age was computed as of the beginning of the study (i.e., October 1, 2008, for the Oregon cohort and October 1, 2009, for the Texas cohort). Math language included teacher models, group responses, individual responses, and teacher-provided feedback. ELM = Early Learning in Mathematics; SS-ELs = Spanish-speaking English learners.

The 66 participating classrooms were taught by 67 teachers; 2 teachers taught half-day schedules in a comparison classroom in Oregon. All teachers participated for the duration of the ELM efficacy trial.

Nested within the 66 classrooms were 556 SS-EL kindergarten students. Of the 556 SS-ELs, 328 and 228 were in treatment and comparison classrooms, respectively. Table 1 provides student demographic information by condition. The average number of SS-ELs was 10.2 (SD = 6.0) in treatment classrooms and 8.2 (SD = 5.2) in comparison classrooms. In ELM and comparison classrooms, 19% and 15% of students, respectively, were eligible for special education services. The average age of SS-ELs in both conditions was 5.6 years, and the sample was predominantly Hispanic (93% in ELM, 92% in comparison). The processes for determining students' eligibility for EL services and instructional programs varied across the participating districts. All districts required parents to complete a home language survey to determine the student's primary home language. However, three districts administered the Woodcock-Muñoz Language Survey–Revised (Riverside Publishing) and identified students as ELs if they scored below Level 4 on both the Oral Language Total and Broad English Ability Total. The fourth district identified kindergarten students as ELs if they scored below 4 on the Pre-LAS 2000 (CTB/McGraw Hill).

ELM Core Curriculum

ELM is a core kindergarten math curriculum that was designed to meet the instructional needs of all students, including typically achieving students, students with math difficulties, and ELs with various first languages. The program consists of four quarterly teacher manuals, each containing 30 daily lessons. Math content is systematically introduced, reviewed, and extended through ELM's explicit instructional design framework. Each manual offers scripted guidelines to support teachers in demonstrating key math content, delivering timely academic feedback, and facilitating deliberate practice opportunities for students, including structured verbal interactions between teachers and students, as well as among students, around key math content. Such practice opportunities are systematically designed to help students build mathematical proficiency and develop mathematical language and vocabulary. To promote conceptual understanding, lessons incorporate opportunities for students to work with visual representations of math ideas, such as 3-day shapes, counting blocks, and number lines.

Math domains targeted in ELM include (a) counting and cardinality, (b) operations and algebraic thinking, (c) number and operations in base 10, (d) measurement and data, (e) geometry, and (f) precise math vocabulary. Daily lessons last approximately 45 minutes and include four to five math activities including (a) whole-class and small-group activities focused on new mathematical content, (b) judicious review activities of previously learned material, and (c) worksheet activities that provide students extended practice with previously taught concepts and skills. Problem-solving activities are introduced every five lessons to help students practice newly acquired problem-solving skills and engage in real-world mathematical problems, such as collecting categorical data and representing the data on a graph. See https://dibels.uoregon.edu/market/movingup/elm for additional information on the ELM curriculum. Treatment teachers implemented the ELM curriculum 5 days per week in whole-class settings.

Professional Development

Treatment teachers received four professional development workshops related to curriculum implementation. Each workshop lasted 6 hours and corresponded with the ELM quarterly teacher manuals. For example, the first workshop was conducted prior to the start of the school year and focused on Lessons 1–30. The remaining workshops occurred in the middle of the fall, winter, and spring quarters. Each workshop centered on critical math concepts and the instructional design and delivery features of the ELM curriculum. Workshops also offered treatment teachers opportunities to practice with sample lessons and receive feedback from the ELM curriculum team.

Treatment Fidelity

Implementation fidelity of ELM lesson activities (i.e., four to five activities per lesson) was assessed three times in each treatment classroom by project staff. For each observed ELM activity, project staff documented whether teachers (a) addressed the targeted learning objectives, (b) followed the teacher scripting, (c) used the prescribed math visual representations, (d) offered student practice opportunities, and (e) provided timely academic feedback. Teachers' adherence to these features within each activity was documented using a rating scale ranging from 0 (*did not implement*) to 0.5 (*partial implementation*) to 1.0 (*full implementation*). The ELM efficacy trial reported moderate levels of fidelity in the fall (M = 0.86, SD = 0.13), winter (M = 0.87, SD = 0.15), and spring (M = 0.87, SD = 0.14) and found no evidence of contamination between ELM and comparison classrooms (Doabler et al., 2014).

Comparison Classrooms

Classrooms randomly assigned to the comparison condition provided standard district practices (business as usual). All comparison classroom teachers were asked to provide 45 minutes of daily math instruction. Instruction in these classrooms entailed teacher-developed activities and a variety of commercially available math curricula, including Everyday Mathematics, Houghton Mifflin, Scott Foresman, Texas Mathematics, and Bridges in Mathematics. Comparison teachers used a variety of instructional formats to deliver instruction, including whole-class instruction, center-based activities, and peer-to-peer learning.

Measures

Students were assessed at pretest and posttest on measures of foundational aspects of number sense and whole-number understanding. The assessment battery included a general outcome measure of students' procedural and conceptual knowledge of whole numbers, as well as a set of early math curriculum-based measures that focused on discrete skills of number sense. Trained project staff administered all student measures and met acceptable interscorer reliability criteria (i.e., .95 or higher) at pretest and posttest with the measures.

Test of Early Mathematics Ability–Third Edition

The TEMA-3 (Pro-Ed, 2007) is a standardized, norm-referenced, individually administered measure of beginning mathematical ability. The TEMA-3 assesses mathematical understanding at the formal and informal levels for children ranging in age from 3 to 8 years 11 months. The TEMA-3 addresses children's conceptual and procedural understanding of math, including counting and basic calculations. The TEMA-3 reports alternate-form and test–retest reliabilities of .97 and .82 to .93, respectively. Concurrent validity coefficients with the Key Math–Revised and Young Children's Achievement Test were .54 and .91, respectively (see Bliss, 2006). Standard scores were used in the analyses.

EN-CBM Measures

EN-CBM (Clarke & Shinn, 2004) consists of four 1-minute fluency-based measures. The Oral Counting measure requires students to orally rote count as high as possible, and the discontinue rule applies after the first counting error. The Number Identification measure requires students to orally identify numbers between 0 and 10. Quantity Discrimination requires students to name which of two visually presented numbers between 0 and 10 is greater. The Missing Number measure requires students to name the missing number from a string of three numbers (0–10), with the unknown number in the first, middle, or last position. Doabler et al. (2015) reported concurrent validity coefficients between EN-CBM total scores and the TEMA-3 scores at pretest (r = .87) and posttest (r = .81). Average test–retest reliability of EN-CBM was reported as .89 (Doabler et al., 2015). A total EN-CBM score was computed as the sum across all subtests and used in subsequent analyses.

Observations of Core Math Instruction

To measure the frequency of math discourse during core math instruction, project staff observed all 129 treatment and comparison classrooms. In Oregon, classrooms were observed three times (fall, winter, and spring). Classrooms in Texas were observed two times (winter and spring). In the aggregate, 314 classroom observations were conducted, with 74 serving as paired observations or interobserver reliability checks. Paired observations had two observers collect data simultaneously to test interobserver agreement. The ELM efficacy trial reported intraclass correlation coefficients (ICCs) that ranged from .67 to .95, suggesting substantial to nearly perfect interobserver reliability (Doabler et al., 2015).

Trained observers documented the frequency of mathematical discourse in both conditions using the Classroom Observations of Student-Teacher Interactions–Mathematics (COSTI-M), a modified version of a classroom-level observation instrument designed by Smolkowski and Gunn (2012). Data were collected on four student–teacher interaction behaviors that pertain to productive mathematical discourse: (a) teacher demonstrations, (b) teacher-provided academic feedback, (c) group responses, and (d) individual responses (Gersten et al., 2009). Mean rates of these four COSTI-M behaviors were calculated by dividing the frequency of each behavior in an observed lesson by the duration of the observation in minutes. Table 1 provides rates per minute for each targeted behavior.

In the COSTI-M, teacher demonstrations reflect a teacher providing mathematical information in an overt and clear manner. Teacher demonstrations are considered a hallmark of explicit math instruction and include a teacher's explanations, verbalizations of thought processes, or physical demonstrations of math content. Academic feedback reflects a teacher's explanation of an incorrect student response or a verification of a correct student response. Group responses entail a concurrent mathematical verbalization from two or more students. When facilitated well, they present an opportunity to engage all students in a mathematical task, such as an entire class stating how the additive identity property applies when adding zero to another whole number. Individual responses reflect one student verbalizing or physically demonstrating the answer to a mathematical problem. These types of responses allow teachers the ability to monitor the mathematical understanding of individual students in core math settings. To avoid coding extraneous conversation, such as student call-outs, group and individual responses were only coded if requested by the teacher.

Statistical Analysis

We assessed the effects of ELM on TEMA-3 standard scores and EN-CBM raw scores with a mixed-model (multilevel) Time × Condition analysis (Murray, 1998) to account for the intraclass correlation (ICC) associated with students nested within classrooms (i.e., the level of random assignment). The analysis tested differences between conditions on change in outcomes from the fall (T1) to spring (T2) of kindergarten, with gains for individual students clustered within classrooms. The statistical model included time, condition, and the Time × Condition interaction, with time coded 0 at T1 and 1 at T2 and condition coded 0 for control and 1 for ELM. Analyses were based on 66 classrooms that included at least one SS-EL and had complete student demographic data about EL status.

We also explored differential response to the ELM curriculum as a function of various student- and classroom-level variables. We expanded the statistical model for this secondary aim to include a predictor and its interaction with condition, time, and the Time × Condition term, resulting in a three-way interaction, all corresponding two-way interactions, and individual (conditional) effects. The three-way interaction of the predictor, time, and condition provided an estimate of whether condition effects varied by the predictor.

Model Estimation

We fit models to our data with SAS PROC MIXED version 9.2 (SAS Institute, 2009) using restricted maximum likelihood. All SS-ELs with pretest or posttest math achievement scores, 97% of the SS-EL sample, were included in the analyses (n = 537 for TEMA-3, n = 542 for EN-CBM). Maximum likelihood estimation with all available data produces potentially unbiased results even in the face of substantial missing data, provided the missing data were missing at random (Schafer & Graham, 2002). In the present study, we did not believe that missing data represented a meaningful departure from the missing at random assumption, meaning that missing data did not likely depend on unobserved determinants of the outcomes of interest (Little & Rubin, 2002). Most missing data involved students who were absent on the day of assessment or transferred to a new school.

The statistical model assumes independent and normally distributed observations. We addressed the first, more important assumption (van Belle, 2008) by explicitly modeling the multilevel nature of the data. Regression methods have been found quite robust to violations of normality, and outliers have a limited influence on the results in a variety of multilevel modeling scenarios (Bloom, Bos, & Lee, 1999; Murray et al., 2006). Murray et al. (2006) showed that violations of normality at either the individual level or group level or at both the individual level and group level do not bias results as long as the study is balanced at the group level.

Effect Sizes

To ease interpretation of results, we computed an effect size, Hedges's g (Hedges, 1981), for each fixed effect. Hedges's g, recommended by the What Works Clearinghouse (WWC, 2014), represents an individual-level effect size comparable to Cohen's d (Cohen, 1988).

RESULTS

Table 2 provides descriptive statistics for the outcome measures used to evaluate the impact of the ELM curriculum among SS-

Table 2. Descriptive Statistics for Outcome Measures by Assessment Point and Condition

	Fall		Spring	
Measure	ELM	Comparison	ELM	Comparison
TEMA-3				
M	77.9	79.7	93.9	90.3
SD	13.7	13.3	13.4	13.0
n	235	148	292	211
EN-CBM				
M	41.0	39.2	137.7	123.8
SD	34.3	33.7	54.7	58.2
n	275	182	290	211

Note. A total Early Numeracy Curriculum-Based Measure (EN-CBM) score, computed as the sum across all subtests, was used in all analyses. ELM = Early Learning in Mathematics; TEMA-3 = Test of Early Mathematics Ability–Third Edition.

ELs. ELM and comparison classrooms did not significantly differ on any demographic characteristics or outcome measures collected at pretest.

Attrition

Examination of attrition between pretest and posttest revealed 9.5% of the student sample did not complete a posttest assessment: 11.0% of the treatment participants compared with 7.5% of the control participants; $\chi^2_{(1)} = 1.93$, $p = .17$. The extent to which attrition threatened the internal validity of this study was evaluated using a mixed-model analysis of variance designed to test whether outcome variables were differentially affected across conditions by attrition. These analyses accounted for students nested within classrooms and examined the effects of condition and attrition status, as well as their interaction, on pretest outcomes. We found no statistically significant interactions between attrition and condition predicting baseline outcomes (ps > 0.71), suggesting that student math scores were not differentially affected by attrition across conditions.

Efficacy

We tested the hypothesis that SS-ELs in ELM classrooms experienced greater gains on the TEMA-3 and EN-CBM during kindergarten than SS-ELs in comparison classrooms. Complete results are summarized in Table 3, including the ICC for gains as described by Murray (1998, p. 301). SS-ELs in ELM classrooms statistically significantly outperformed SS-ELs in comparison classrooms on the TEMA-3 ($g = 0.30$, $p = .04$). A nonsignificant, albeit positive, effect was obtained for the EN-CBM ($g = 0.18$, $p = .17$).

After we accounted for treatment condition, significant variation remained among students within classrooms in initial achievement on the TEMA-3 (estimate = 99.60, $p < .01$) and EN-CBM (estimate = 927.99, $p < .01$). Significant variation also remained between classrooms in mean initial achievement on EN-CBM (estimate = 291.61, $p = .01$) and in mean gains from the fall to the spring of kindergarten on the TEMA-3 (estimate = 14.87, $p = .01$) and EN-CBM (estimate = 232.31, $p = .01$).

Differential Response

The Predictor × Time × Condition row in Table 4 addresses our research questions concerning differential response to ELM. For each outcome measure, we tested for differential response to ELM as a function of (a) pretest student performance as measured by the TEMA-3 and (b) the following classroom characteristics: number of ELs in the classroom; rate of group responses; rate of individual responses; rate of group and individual responses combined; and rate of teacher models, group responses, individual responses, and teacher-provided feedback combined. None of the Predictor × Time × Condition interactions were statistically significant or even approached statistical significance (ps > 0.47). Thus, our analyses were unable to offer clear evidence of differential response to ELM among SS-ELs. Furthermore, we do not expect that low statistical power explained the nonsignificant findings for differential response.

Table 3. Results From Mixed-Model Analyses

Effect or Statistic	TEMA-3	EN-CBM
Fixed effects		
Intercept	78.40*** (1.52)	35.49*** (5.51)
Time	11.86*** (1.46)	85.61*** (5.31)
Condition	−0.85 (2.02)	2.64 (7.43)
Time × Condition	3.98* (1.96)	9.98 (7.18)
Variances		
Residual	53.25*** (4.26)	805.44*** (60.09)
Student intercept	99.60*** (9.06)	927.99*** (98.29)
Classroom intercept	14.43 (8.06)	291.61* (119.84)
Classroom gains	14.87** (4.84)	232.31*** (69.08)
ICC (ρ)		
Classroom gains	0.218	0.224
Hedges's *g*		
Time × Condition	0.30	0.18
p Value		
Time × Condition	.047	.170

Note. This table presents results from mixed-model Time × Condition analyses for tests of condition effects on fall-to-spring gains in Test of Early Mathematics Ability–Third Edition (TEMA-3) and Early Numeracy Curriculum-Based Measure (EN-CBM) scores. Data are presented as parameter estimates with standard errors in parentheses except for intraclass correlation coefficient (ICC), Hedges's *g*, and *p* value. Tests of fixed effects used 59 *df*. A total EN-CBM score, computed as the sum across all subtests, was used in all analyses.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

DISCUSSION

This study examined the impact of a 120-lesson core kindergarten math curriculum on the math achievement of SS-ELs. For SS-ELs in ELM classrooms, there was a significant effect on one of the two outcome measures, the TEMA-3. The impact on the second outcome measure, EN-CBM, was positive but nonsignificant. Overall, results would be classified as a "statistically significant positive effect" (WWC, 2014). Analyses examining differential response found no difference in response to ELM for SS-ELs by initial skill status, the number of SS-ELs in the classroom, and a set of student–teacher interaction behaviors theorized to facilitate mathematical discourse used in core math instruction.

We believe the finding that initial skill status, as measured by the TEMA-3 at the beginning of kindergarten, did not influence the impact of ELM for SS-ELs is encouraging because it suggests that ELM essentially had the same positive impact for all SS-ELs regardless of the amount of informal math knowledge they had prior to school entry. In other words, ELM seemed to work equally well across a range of skill levels. It may be that the instructional design features of the ELM curriculum are configured in a manner that can help support the majority of SS-EL kindergarten students in developing early math proficiency. For example, SS-ELs may gain a deep understanding of how numbers work through ELM's sequence of instruction, which strategically intersperses concrete instructional examples with abstract representations of numbers. SS-ELs, and ELs in general, may also benefit from the way in which ELM uses simpler instructional examples rather than complex ones to introduce and teach new math concepts and vocabulary. It is plausible that these introductory instructional examples and problem contexts help engage the existing understandings and experiences of SS-ELs

Table 4. Tests of Predictors of Differential Response

Effect or Statistic	Predictor of Differential Response					
	Pretest TEMA-3	ELs in Classroom	Grp Rate	Ind Rate	Grp or Ind Rate	Math Language Rate
Fixed effects						
Intercept	78.61*** (0.87)	76.78*** (1.78)	78.28*** (1.57)	78.50*** (1.53)	78.27*** (1.57)	78.19*** (1.59)
Time	13.70*** (1.25)	13.12*** (1.70)	11.44*** (1.50)	11.78*** (1.50)	11.60*** (1.52)	11.45*** (1.55)
Condition	0.00 (1.16)	0.76 (2.23)	–1.32 (2.11)	–1.19 (2.06)	–1.34 (2.12)	–1.30 (2.13)
Time × Condition	3.64* (1.66)	2.92 (2.13)	5.14* (2.03)	3.74 (2.04)	4.69* (2.07)	4.83* (2.09)
Predictor	1.00*** (0.04)	–0.54 (0.31)	–0.95 (2.02)	–1.35 (4.83)	–0.95 (1.80)	–0.79 (1.19)
Predictor × Condition	0.00 (0.05)	0.30 (0.39)	2.85 (3.04)	5.41 (6.74)	3.22 (2.68)	2.25 (1.75)
Predictor × Time	–0.40*** (0.06)	0.41 (0.30)	–2.19 (1.93)	3.64 (4.73)	–1.19 (1.73)	–1.02 (1.16)
Predictor × Time × Condition	–0.03 (0.07)	0.09 (0.37)	–2.07 (2.90)	–3.53 (6.66)	–1.86 (2.58)	–.84 (1.70)
Variances						
Residual	37.33*** (2.91)	52.95*** (4.23)	53.03*** (4.30)	52.92*** (4.29)	53.00*** (4.30)	53.00*** (4.30)
Student	0.00 (2.03)	99.42*** (9.03)	97.47*** (9.05)	97.34*** (9.02)	97.16*** (9.02)	97.15*** (9.01)
Classroom intercept	0.00 (2.24)	15.37 (8.20)	14.18 (8.08)	13.98 (8.36)	14.52 (8.29)	13.69 (8.09)
Classroom gains	10.22** (3.21)	14.12** (4.66)	13.83** (4.63)	16.34** (5.36)	15.13** (4.93)	15.15** (4.94)
p value						
Predictor × Time × Condition	.7144	.8059	.4772	.5975	.4744	.6228

Note. The table presents tests of predictors of differential response to condition on gains in Test of Early Mathematics Ability–Third Edition (TEMA-3) standard scores. Data are presented as parameter estimates with standard errors in parentheses. ELs = English learners; Grp = group response; Ind = individual response; Math language = rate of teacher models, group response, individual response, and teacher-provided feedback combined.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

and, in turn, allow them to achieve early success with new math content.

The finding of no differential response based on the initial skill levels of SS-ELs is also somewhat surprising given that a previous study of ELM (Clarke et al., 2011) revealed that the curriculum was more effective for students considered at risk for math difficulties at the start of the kindergarten year (i.e., TEMA-3 pretest scores at or below the 40th percentile on the TEMA-3) than for students considered on track for developing mathematical proficiency (i.e., TEMA-3 pretest scores above the 40th percentile on the TEMA-3). While only 11% of SS-ELs in the current sample tested above the 40th percentile on the TEMA-3 at pretest, we believe a strong case can be made from this study that typically achieving SS-ELs, like their SS-EL peers who are at risk for math difficulties at the start of kindergarten, may require explicit and systematic core math instruction given their limited proficiency in the English language. Converging evidence from investigations of the Early Childhood Longitudinal Study–Kindergarten cohort indicate that early math skills acquired in kindergarten are critical for acquiring proficiency in later math and building knowledge in other content areas, including reading and science (Classens & Engel, 2013, Duncan et al., 2007, Morgan et al., 2009). Therefore, it seems reasonable that all ELs may need an explicit and systematic core math curriculum to make a successful start in kindergarten math and begin to tackle the double demands of simultaneously learning the languages of English and math.

Limitations of the Study

A number of critical limitations should be considered when examining the findings from the study. First, the designation of a student as an EL was based on district methodology that varied widely across the participating districts. In part, this reflects the reality of actual practice (Sullivan, 2011). Thus caution should be exercised in extrapolating results of the current study to students and districts that may employ different classification methods. A second limitation was the study's lack of a measure of English proficiency. This absence prevented us from examining whether students' proficiency with English moderated the treatment effects. As with any study conducted within a unique geographic and demographic sample, a focus should be on replicating results across an array of diverse sites and participants (Cook, 2014).

Another limitation is that only two observations in the Texas classrooms were conducted using the COSTI-M. The decision to limit the number of COSTI-M observations was based primarily on the availability of trained observers. Nonetheless, two observations in Texas may explain the lack of significance for differential response to ELM as a function of the rate of productive math discourse in Tier 1 settings. The tactic used to measure math discourse opportunities for SS-ELs is another limitation. In the ELM efficacy trial, productive math discourse was coded at the classroom level. Consequently, opportunities for SS-ELs to verbally convey their mathematical thinking may have been confounded by the verbalizations of non-ELs.

There is also some concern about how directly we were able to evaluate math performance on the content taught as part of the ELM curriculum. Given that ELM addresses multiple math domains (i.e., counting and cardinality, operations and algebraic thinking, number and operations in base 10, measurement and data, geometry, and precise math vocabulary), our use of the TEMA-3 and EN-CBM as outcome measures may not have aligned fully with the content coverage of ELM. The TEMA-3 focuses primarily on whole-number understanding, and the EN-CBM measures focus on discrete aspects of number sense (e.g., magnitude comparison). These foundational skills are covered early in the scope and sequence of ELM's first quarterly teacher manual. Future research should use a more proximal assessment that directly links to the concepts taught across the math domains of ELM.

Another important issue to consider is the use of English-based math assessments. While the primary first language of this study's sample was Spanish, all math assessments were administered in English. Consequently, potential language barriers may have affected SS-ELs' pretest and posttest performances. Future research involving SS-ELs should administer standardized math assessments in both English and Spanish. This would allow for comparisons between students' math skills in English and Spanish.

Last, it should be noted that while we theorize that the instructional architecture of ELM was the primary agent affecting outcomes, treatment teachers were provided professional development on the ELM curriculum and on effective teaching strategies and behaviors. While the professional development was primarily centered on ELM components and implementation, a stronger research design would have controlled for the impact of professional development by providing comparison teachers with general experiences on teaching strategies and behaviors. Doing so would have eliminated professional development as an alternate possible cause and confounder when interpreting the study results.

Implications for Future Research and School Psychologists

Future research should explore the potential of differential impact based on levels of English proficiency among ELs with a variety of first languages, including Spanish. In this study, we were unable to obtain English proficiency scores for participating students. Therefore, it is difficult to conclude whether SS-ELs with lower English proficiency would have responded differently to the ELM curriculum. Regardless, collecting English language proficiency data is of high importance, particularly as the field moves to implementing Multi-Tiered Systems of Support (MTSS) in mathematics (Clarke et al., 2011; Fuchs, Fuchs, & Compton, 2012). English language proficiency data can help ensure the range of learner needs is appropriately considered when providing instructional support within an MTSS.

School psychologists are uniquely positioned to help schools and districts think systematically about building effective MTSS in mathematics. For example, school psychologists can assist schools and teachers in evaluating the effectiveness or quality of Tier 1 math instruction. Core math instruction is intended to serve as a valuable first line of defense in preventing math difficulties and accelerating the math achievement of at-risk learners. Therefore, school psychologists can provide strong insight into which ELs are likely to respond to Tier 1 core math instruction. Establishing the impact of a core math curriculum for ELs will also help determine if failure of an EL student to make sufficient growth is the result of lower levels of English language skills or because of difficulties specific to math. That is, if the core curriculum is effective for ELs in general, an EL's nonresponse could more readily be attributed to a true deficit in math. In an MTSS, these ELs would be considered in need of a Tier 2 intervention. Because research on math instruction for ELs is severely limited (Richards-Tutor et al., 2016), future studies should not only focus on the effectiveness of core curricula but also be linked to ongoing efforts to develop and evaluate effective Tier 2 and 3 interventions (Gersten et al., 2009). As a result, this will better allow schools the opportunity to provide a full continuum of intensive support for ELs struggling with math.

In addition, school psychologists will be able to assist teachers in examining core math programs for the presence of validated instructional design and delivery principles, such as overt teacher demonstrations and deliberate verbalizations of math concepts. Core math programs are integral components of an MTSS. We hypothesized that ELM's architecture of instruction would be a key ingredient in affecting student outcomes because of its incorporation of explicit instructional design and delivery principles. To some extent, this general hypothesis was supported as ELM had a positive impact on the math achievement of SS-ELs. However, additional analyses revealed the effect of the ELM curriculum did not vary as a function of rates of math discourse during core math instruction (e.g., rate of group responses). In other words, the impact of ELM was essentially the same between classrooms with high and low rates of math discourse opportunities. While the results suggest that the rate of discourse opportunities did not surface as a predictor of treatment response for SS-ELs, the nature of the ELM curriculum may have obscured the importance of math verbalizations. That is, because ELM is a scripted curriculum and thus ensures multiple opportunities to engage in math discourse, each ELM classroom may have provided, at a minimum, the math verbalizations needed for SS-ELs to benefit and, once the minimum threshold was met, there was a limited impact above and beyond that threshold.

Research suggests that language-intensive math instruction is critical to students' development of math knowledge (Doabler et al., 2015; Gersten et al., 2009). However, less is known about when math discourse opportunities should take place during the learning process and to what extent they should be cognitively demanding for students, including those with limited proficiency in English. Future investigation of these areas is warranted along with considering the quality of the math verbalization opportunities ELs receive during core math instruction. This triad approach of documenting the quantity, quality, and cognitive demand of math verbalizations would likely provide a more comprehensive picture of whether all students, including ELs, are receiving effective, evidence-based math instruction and meaningful access to grade-level math content.

CONCLUSION

Despite the preponderance of evidence that a successful start in math is critical for all students (Classens & Engel, 2013; Morgan et al., 2009), as well as the fact that a concerning number of ELs are struggling to acquire proficiency in math (NCES, 2013), there is an alarming shortage of empirical literature on effective math instruction for ELs (Janzen, 2008; Richards-Tutor et al., 2016). The current study addresses the urgent need for research in this critical area. While findings from this study are limited, they do indicate promise and should serve as a watershed for future research. It is hoped that future studies will allow the field to begin building a research base on effective instructional practices for teaching mathematics to ELs.

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Date Received: December 2, 2014
Date Accepted: June 29, 2015
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Ben Clarke, PhD, is an associate professor in the School Psychology Program at the University of Oregon. He currently serves or has served as a principal investigator on 14 federally funded research grants in the area of mathematics instruction focused on the development and efficacy testing of intervention programs spanning the kindergarten through sixth-grade spectrum in both traditional and technology-based formats.

Derek B. Kosty, PhD, is a senior data analyst at Oregon Research Institute. His research interests include research design, multilevel data analysis, longitudinal modeling, and multivariate statistics for evaluating the impact of educational and behavioral interventions as well as the mechanisms through which they operate. Dr. Kosty has served as a data analyst or methodology consultant on 15 federally funded research grants since 2007. Currently, Dr. Kosty is interested in the etiology of problematic cannabis use and its relation to psychosocial functioning including self-regulation and academic engagement.

Scott K. Baker, PhD, is a research professor at the Center on Research and Evaluation at Southern Methodist University. Dr. Baker is interested in the role scientific research can play in improving policies and practices associated with child outcomes. He has been the principal investigator on numerous education grants from the Institute of Education Sciences and other federal agencies. Currently, Dr. Baker is interested in the impact of interventions on child outcomes, mechanisms that underlie effective interventions, and how intervention impact varies by factors intrinsic and extrinsic to the child.

Keith Smolkowski, PhD, is a research scientist at Oregon Research Institute. His research interests include social and academic behavior of school-age children within the fields of education, public health, and prevention science, as well as the methodologic aspects of the design and analysis of complex research studies. He received his doctorate in special education from the University of Oregon.

Hank Fien, PhD, is principal and coprincipal investigator on 10 Institute of Education Sciences grants in the areas of early reading, adolescent reading, and early mathematics interventions for diverse learners in school settings. His research interests include reading and mathematics development in young children, instructional design, and empirically validated interventions aimed at preventing or ameliorating student academic problems. Dr. Fien's most recent work is focused on extending the learning environment from the physical classroom to include virtual environments (e.g., gaming platforms) and leveraging gaming technology to maximize instructional design and delivery principles.