

**Validation of the Effectiveness of an Innovative  
Early Mathematics Intervention for High-Need Students**

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**PROJECT NARRATIVE**  
**Validation of the Effectiveness of an**  
**Innovative Early Mathematics Intervention for High-Need Students**

**Project Rationale and Design<sup>1</sup>**

All citizens need a broad range of basic mathematical skills and understanding to make informed decisions in their jobs, households, and communities. Careers in the 21st century require an increasing level of proficiency in mathematics (Glenn Commission, 2000; U.S. Dept. of Labor, Bureau of Labor Statistics, 2000). A series of national and international assessments of mathematics achievement, however, has revealed an overall level of proficiency in American students well below their peers in several other countries and below what is desired and needed (Kilpatrick, Swafford, & Findell, 2001; Mullis et al., 1997; Mullis et al., 2000). In response to these concerns, the adoption of world-class math standards by American schools has been recommended (National Council of Teachers of Mathematics; National Mathematics Advisory Panel, 2008). Most states recently adopted and are beginning to implement the Common Core State Standards for Mathematics (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010). In broad outline, these standards address the “mile-wide and inch-deep” mathematics curriculum currently used in American schools by focusing on a narrower and deeper (i.e., mathematically central or foundational) set of standards. This approach is similar to that used in several nations with higher math achievement (e.g., NCES, 2008). These Common Core math standards are intended to help schools raise mathematics achievement of American students to levels approaching that of other countries.

A major challenge educators face in implementing these standards, however, arises immediately in grade K with the first set of Common Core math standards. Elementary schools are expected to align instruction with the higher learning expectations built into the new standards, but teachers still face the unsolved problem that many children enter school unprepared for the mathematics curriculum in grade K (National Research Council, 2009). Gaps in early math knowledge are especially pronounced for children from low-income and minority

<sup>1</sup> *Links between selection criteria of the RFA and sections of this grant proposal are given in Appendix J, pp. J2-J3.*

backgrounds, with socioeconomic- (SES-) related gaps being larger than gaps related to other demographic characteristics (Duncan & Magnuson, 2011; Duncan & Siegler, 2012). At the end of pre-K, many low-SES children are almost one year behind their middle-class peers in math knowledge – a substantial difference at such an early age (Starkey & Klein, 2008). Left unaddressed, an abundance of research shows that this gap persists and increases over time (Anunola et al., 2004; Entwisle & Alexander, 1989, 1990; Jordan, Huttenlocher, & Levine, 1992; Morgan, Farkas, & Wu, 2009; Rampey, Dion, & Donahue, 2009; Rathbun & West, 2004). This will make implementation of the Common Core mathematics standards an ongoing challenge at grade levels beyond K.

Our proposed project is designed to provide an effective early math intervention, comprised of effective curricula, practices, and implementation strategies, that elementary schools can implement to close the SES-related math gap among pre-K and K students. This intervention will help the nation's schools raise mathematics achievement for all students.

### **Absolute and Competitive Preference Priorities**

The proposed project will validate the effectiveness of the pre-K and K components of our early mathematics intervention when combined and implemented on a statewide scale. We will establish whether, and to what extent, public schools can close the early math gap in economically disadvantaged children, and thereby prepare them for instruction aligned with the Common Core math standards. The intervention will be executed in a manner that (1) is consistent with our prior research evidence supporting the proposed project, and (2) aligns with Absolute Priority 2 and Competitive Preference Priorities 6 and 8.

**Absolute priority.** We address **Absolute Priority 2** – Innovations that promote STEM education, by “increasing the number of individuals from groups traditionally underrepresented in STEM ... who are provided access to rigorous and engaging coursework in STEM” and by “increasing the opportunities for high-quality ... professional development for teachers or other educators of STEM subjects.” School district staff (math specialists/trainers, as well as pre-K and K teachers) will be provided professional development in effective early math practices and

curricula. Teachers, with ongoing support from math specialists/trainers in their district, will then provide students with instruction and progress monitoring that is well aligned with the high quality and rigorous math content demanded by multiple organizations (NCTM, 2008; NMAP, 2008; NRC, 2009). This instruction will enable high-need students from low-SES backgrounds, including underrepresented minority and LEP students, to achieve at the levels required by the Common Core math standards.

**Competitive preference priorities.** We address **Competitive Preference Priority 6 – Innovations for Improving Early Learning Outcomes**, in particular (a) improving young children’s school readiness in mathematics, (b) improving and aligning early developmental milestones and standards in mathematics with appropriate outcome measures, and (c) improving alignment, collaboration, and transitions between early learning programs that serve children in preschools, and in lower elementary school. We do so by (a) providing children with an effective two-year math intervention from pre-K through grade K, and (b) aligning precursory informal math skills and concepts in preschool, developed with support from the pre-K component of the intervention, with the 9 intermediate clusters of standards that are comprised of the 35 Common Core math standards for grade K. Furthermore, (c) we will train math specialists/local trainers to work with pre-K and K teachers to build math support systems that ensure a successful transition from pre-K to K to grade 1. Specifically, trainers will help teachers begin implementing a shared data system to track individual children’s mathematics growth. As part of the pre-K component of the intervention, each child will be assessed formatively, throughout the year, and summatively, at the end of the year, on their understanding of foundational knowledge underlying the Common Core Math Standards for K. Kindergarten teachers will receive data reports from pre-K teachers documenting each child’s developing mathematical concepts and skills that correspond to the 9 intermediate clusters of standards linked to the 35 Common Core math standards for K (see **Tables 1, 2, 3, Appendix J, pp. J4-J9**). The same process will be followed during the K component of the intervention, so that grade 1 teachers will receive data reports from grade K teachers documenting each child’s concepts and skills that correspond to

the 35 Common Core math standards for K and, therefore, their readiness for learning the Common Core math standards for grade 1.

We also address **Competitive Preference Priority 8** – Innovations to Address the Unique Learning Needs of Students with Disabilities and Limited English Proficient Students. A number of features of the proposed work are aligned with this priority. First, our official LEA partners have a high percentage of pre-K and K children who are from low-SES backgrounds and many (approximately 30%) of these children are English Language Learners (ELL). Our target sample will be pre-K children from low-income families who qualify for categorical state-funded preschool, Head Start, or Title 1 classrooms. Second, the pre-K and K components of our math intervention target the learning needs of both native English speakers and ELLs. English and Spanish versions of home math activities will be provided for parents to use with their children at home, and teachers will be provided with key mathematical language in both English and Spanish for bilingual delivery of math activities for LEP children who need this support. Across both the pre-k and K components, an emphasis is placed on building academic language through vocabulary instruction and meaningful opportunities for students to engage in discourse related to mathematics. Lastly, both were specifically developed to include design elements and instructional strategies found to be particularly effective for young children struggling with mathematics achievement and at risk for mathematical learning disabilities (Baker, Gersten, & Lee, 2002; Gersten et al., 2009). They incorporate principles associated with differentiated instruction and individualized learning opportunities. For example, both the pre-K and K components recognize that an individual child's success will occur at different rates, and thus, they include upward and downward extensions to ensure that the needs of all students are met.

### **Principal Project Goals**

The principal goal of this proposed project is to implement an effective and innovative early mathematics intervention for economically disadvantaged pre-K and K students. The intervention will close the SES-related gap in early mathematical knowledge by the end of kindergarten and enable them to achieve in classrooms implementing curricula aligned with the

Common Core mathematics standards. Our exceptional approach is to mathematically enrich children's early learning environments over two years in both public pre-K and K classrooms and at home. It is widely accepted that intervention is easier and more effective when conducted earlier in life than later (e.g., Lazar & Darlington, 1982; Ramey & Campbell, 1984).

Our own work has demonstrated that children's early mathematical knowledge can be enhanced significantly by providing their PK and K teachers and parents with effective materials and guidance in using them (Clarke et al., 2011; Klein, et al., 2008). At present, however, most public preschool and kindergarten programs spend little time on mathematics. In a recent study of 730 PK and K classrooms, PK children spent only 6% of their school day engaged in math learning; K children spent only 11% of their on math (LaParo, et al., 2009). Likewise, preschool programs are not using effective mathematics curricula. The general curricula that are most widely used by Head Start and state preschool programs have not been found to be effective when tested in a rigorous evaluation (Preschool Curriculum Evaluation Research Consortium, 2008). Also, a recent national RCT of the effectiveness of Head Start found the program not to be effective in the domain of mathematics (Administration for Children and Families, 2005).

A similar need for effective mathematics curricula exists at grade K. Currently, there is no mathematics curriculum listed on the What Works Clearinghouse (WWC) that has been tested at grade K and rated as effective.

Compounding the lack of evidence-based curricula is that most early math curricula share two common design flaws. First, the content included is too broad and thus fails to systematically focus on building student understanding of high priority content (NMAP, 2008). Second, most curricula are not designed to address the specific needs of at-risk students, including students from low-income backgrounds. Since this group of students makes up such a large percentage of the student population, this oversight is glaring. Reviews show that current curricula do not adequately address instructional design elements shown to be effective for at-risk learners (Doabler, Fien, Nelson-Walker, & Baker, 2011; NMAP, 2008; Sood & Jitendra, 2007). Thus, an at-risk student is likely to enter first grade having been exposed to curricula

demonstrating little or no evidence of effectiveness, lacking in content focus, and not including basic instructional principles that are necessary for students who may be at risk for math difficulties.

Our prior evidence (see **Appendix D**) has shown that children’s early mathematical knowledge can be enhanced significantly by providing their pre-K and K teachers and parents with effective materials and guidance in using them. At present, however, most public preschool programs are not using effective mathematics practices or curricula. The general curricula that are most widely used by Head Start and state preschool programs were not been found to be effective in a rigorous evaluation (Preschool Curriculum Evaluation Research Consortium, 2008). A similar need for effective mathematics curricula exists at grade K. Currently, there are no kindergarten mathematics curricula on the What Works Clearinghouse that have been tested at grade K and rated as effective. The math intervention we propose below provides effective mathematics instruction at pre-K and K, and it is based on rigorous experimental evidence. It is not in widespread use, however, because it is relatively new and our efforts have been focused on evaluating its effectiveness.

To achieve the goal of accelerating the early mathematics learning of high-need students, we will employ an exceptional strategy of implementing an effective mathematics intervention at both pre-K and K. The proposed intervention targets economically disadvantaged children’s classroom and home learning environments. The pre-K and K components of this intervention are aligned closely in relation to mathematics content and instructional features. As illustrated in the Common Core Mathematics alignment chart (**Tables 4 and 5, Appendix J, pp. J10-J11**), the pre-K math activities prepare children for clusters of math standards in K, and the K math lessons prepare students for the math standards at grade 1. In addition, both components use instructional design principles critical for students struggling in mathematics (e.g., Gersten et al., 2009; NMAP, 2008), including (1) use of concrete materials in mathematics activities, (2) teacher-guided, scaffolded instruction, (3) multiple opportunities to engage with, discuss, and practice critical mathematics content, (4) mathematics content that varies in difficulty to serve

the developmental range encountered among young, high-need learners, (5) math activities that enrich both the classroom and home learning environments of young children, and (6) individualized monitoring of children's progress in mathematics. The professional development model used to train pre-K and K teachers to implement with fidelity includes a combination of multi-day workshops and bi-weekly training and implementation monitoring in their classrooms for the initial year of implementation. Training and implementation procedures for the intervention are described in the **Research Methods** section below.

A second goal of this project is to track overall school achievement by children who have received our effective early mathematics intervention. A recent meta-analysis of several large longitudinal studies found that children's overall achievement in elementary school is better predicted by their mathematical knowledge in K than by early literacy knowledge, attention skills, or socioemotional development (Duncan, et al., 2007; Duncan & Magnuson, 2011; Duncan, & Siegler, 2012). For example K math knowledge is a stronger predictor than K literacy of later math knowledge, and K math knowledge is equal to K literacy in predicting later literacy. These studies, however, were essentially observational studies and did not experimentally manipulate children's early mathematical knowledge. An important next step for educational research is to determine whether experimental enhancement of children's mathematical knowledge in K results in better overall school achievement later in elementary school. Thus, we propose to follow our sample of children longitudinally and collect data on school achievement in grade 1 in multiple subject areas.

### **Theoretical Framework and Model of Causation**

Educational interventions can fail either because they have an inadequate theoretical foundation or because they are implemented poorly. For that reason, we will first address theoretical considerations guiding our intervention. Later, we will detail our training and implementation procedures.

**The early development of mathematical cognition.** We assume that the primary conceptual foundations of children's early mathematical knowledge are the cognitive domains of

number and space. These domains are partly structured during infancy (Geary, 1994; Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1990). The constraints imposed by this partial structuring enable children to attend to and assimilate mathematically relevant inputs from the environment (Gelman & Williams, 1998). Children first develop informal mathematical knowledge – knowledge that depends upon the presence or mental representation of sets of concrete objects (Piaget, 1952). This knowledge develops considerably during the first three years of life (Baroody, 2004; Starkey, 1992), and children often have several mathematical competencies when they enroll in preschool at age three (Bisanz, et al., 2005; Ginsburg, Klein, & Starkey, 1998). The extent of children’s knowledge at the beginning of preschool, however, depends on their developmental history, especially the mathematically relevant inputs they received in the first three years of life. Informal mathematical knowledge continues to develop during the preschool years and beyond, and research has identified some of the developmental sequences that occur (e.g., Baroody, 2004; Ginsburg, et al., 1998; Sophian, 1996). The significance of informal mathematical knowledge is that it serves as a conceptual foundation for the acquisition of formal mathematical knowledge – the ability to use abstract numerical notation such as the written numerals (1, 2, 3, etc.) and arithmetic operation signs (+, -, etc.). The transition to formal mathematical knowledge begins at age 4-6 years, depending on children’s culture and socioeconomic status (Starkey & Klein, 2003).

**Theory of learning environments embodied in the intervention.** Children’s early mathematical knowledge is constrained by a developmental niche (Super & Harkness, 1996), comprised primarily of the home and school learning environments. The mathematical support provided in children’s niches partly determine the foundation of informal mathematical knowledge they develop. Mathematical knowledge develops primarily in, or as a consequence of, social activity settings (Vygotsky, 1978) – specifically, settings comprised of children actively participating in concrete mathematics activities with teachers or parents who scaffold their learning. Therefore, math instruction is most effective when teachers possess (a) knowledge of mathematical content, (b) knowledge of milestones in early mathematical development, and

(c) knowledge of how curriculum activities can be sequenced to coincide with known sequences in early mathematical development.

**Model of causation.** A causal model is presented in Figure 1 (see **Appendix J, p. J12**) to depict the causal relation between the 2-year mathematics intervention and students' mathematical knowledge. The six main elements are (1) the intervention, which contains the active ingredients that can cause change in students' mathematical knowledge, (2) professional development (PD) support in mathematics for teachers, (3) proximal teacher outcomes produced by the PD, (4) mediation, modeled as aspects of teacher-guided mathematical activities that engage students' mathematical cognition, (5) moderation variables, which are variables at multiple levels that may moderate effects of the intervention, and (6) student outcomes, which are changes in students' mathematical knowledge that result from the intervention.

The active ingredients in the intervention are modeled as the mathematics content from the *Pre-K Mathematics* and *Early Learning of Mathematics* curricula that are aligned with Common Core State Standards for Mathematics. Intensive and frequent PD will be the primary means through which teachers become able to deliver the curriculum with both fidelity and understanding (cf., Shulman, 2000). The in-depth, domain-specific PD support that teachers will receive – math focused workshops and on-site training aligned with the mathematics curricula - will ensure that they (a) learn the essential mathematics content comprising the scope and sequence of the math curricula, (b) learn to implement with fidelity, including delivery of that content, (c) are able to support student engagement and learning of mathematics through explicit, teacher-guided instruction, and (d) become able to connect Common Core standards for mathematical practices to mathematical content in their mathematics instruction.

We expect that teaching essential mathematics content through effective delivery techniques in school classroom settings will change the nature of teaching and learning opportunities for students. Thus, we predict that the mathematics experiences of students will be different in treatment schools than in control schools, and we expect that the frequency and topography of the instructional interactions between teachers and students will be different in

treatment schools than in control schools. At the pre-K level, for example, treatment students will spend more time than control students engaged in developmentally sensitive, teacher-scaffolded small-group mathematics activities. At the K level, treatment students will spend more time than control students engaged in mathematics activities aligned with the Common Core math standards. The impact of the intervention in treatment schools may be *moderated* by variables at multiple levels, which we will test in moderation analyses. The figure gives examples of potential moderators at the levels of student, teacher, and school. We predict that implementation of the intervention as intended will have a positive and direct causal effect on students' mathematical knowledge.

### **Components of the Innovative Intervention**

**Pre-kindergarten component.** *Pre-K Mathematics* (Klein & Starkey, 2004b) is innovative because it was the first pre-K mathematics intervention to be developed and rigorously evaluated, beginning in the 1990s and continuing to date (Klein, et al., 2008; Starkey & Klein, 2000). It has now been combined with an effective K component to enable teachers to support early mathematical development longitudinally over a 2-year period. *Pre-K Mathematics* includes math activities that target the pre-K classroom and home learning environments of young children (**Appendix J, pp. J13-J17**). The set of classroom math activities provide conceptually broad support for the development of children's informal mathematical knowledge.

The intervention consists of *small-group math activities* with concrete manipulatives and a *math learning center* for the pre-kindergarten classroom. The mathematical content of activities is based on developmental research about the nature and extent of early mathematical knowledge (e.g., see Geary, 1994 and Ginsburg et al., 1998 for reviews of research). Units and activities within the Pre-K component prepare children for each of the clusters of standards included in the proposed *Common Core State Standards for Mathematics* (**Appendix J, pp. J4-J5**). They are also explicitly linked to NCTM Focal Points (NCTM, 2008). Downward (less challenging) extensions of the math activities are provided for children who are not ready for a given activity, and upward (more challenging) extensions are included for children who

complete an activity easily. Assessment sheets that accompany each math activity enable the teacher to record individual children's learning over the course of the year. A progress monitoring instrument is used for teachers to track children's mastery on key mathematical content. Teachers also send Spanish or English versions of math activities home to parents during the pre-K year. Teachers receive training in reaching out to parents to conduct these activities with their children and to return a Parent Feedback Form about their use of these activities (**Appendix J, p. J18**).

**Kindergarten component.** The second component of the intervention is an evidence-based K component, *Early Learning in Mathematics (ELM)* (Chard, et al., 2008). This component has also been found to be effective in a randomized control trial, and three additional large studies are currently underway. ELM consists of 120 math activities, 45 minutes in duration, supplemental 15-minute calendar activities, and activities that are sent home for parents (also in Spanish or English) to use with their children. Mathematical content of activities includes whole numbers and operations, geometry, and measurement and requires use of concrete materials by children. Mathematical vocabulary used in these activities is designed to increase the amount of math discourse and use of critical mathematics vocabulary. The three content strands for ELM mirror the three kindergarten focal points specified in the NCTM focal points (2008) and expected learning outcomes for ELM match the Common Core Standards (2010) (See **Appendix J, p. J19-J23**). In *Whole Number and Operations*, ELM places an emphasis on building number sense. Although multiple definitions of number sense have been offered and the construct is not fully articulated (Berch 2005; Dehaene, 1997), Gersten and Chard (1999) provided a definition that targeted some important central features: "...a child's fluidity and flexibility with numbers, the sense of what numbers mean, and an ability to perform mental mathematics and to look at the world and make comparisons" (p. 20). ELM attempts to build that flexibility across a number of critical number concepts advancing students from one-to-one correspondence, efficient counting strategies, how to compose and decompose numbers, work in beginning addition and subtraction, and solving simple addition and subtraction story

problems. In the *Geometry* strand, ELM builds geometric and spatial understanding as students develop increasingly sophisticated spatial understanding (Clements & Sarama, 2007; Van de Walle, 2001). Specific objectives include recognizing attributes and names of 2 and 3-dimensional shapes and recognizing and extending patterns. In the last content strand, *Measurement*, students use measurement to compare and describe quantities and begin work in using standard and non-standard units of measurement.

**Why we expect these strategies and goals to be successful.** The success or failure of educational interventions depends primary on two factors – theory and implementation. Our intervention is based on a well articulated theory (see above) that reflects current thinking about early mathematical development and the learning environments in which early mathematical knowledge is acquired. Furthermore, the effectiveness of the intervention approach we follow has considerable empirical support (**Appendix D**). Finally, our extensive experience – and track record of effectiveness - implementing early math interventions in public pre-K and K programs insures that we have a good understanding of the implementation challenges that teachers and schools face and have developed tools and systems to help teachers and schools implement this mathematics intervention effectively and with fidelity.

### **Costs, Benefits, and Use of the Intervention Beyond the Grant Period**

**Number of students served and estimate of costs.** The number of students who will receive the pre-K and/or K math component of the intervention will be approximately 37,872 (see Table 6, **Appendix J, p. J24**). When costs of the independent evaluation by Westat are included, the per student cost is \$396 for this \$15,000,000 project. When the evaluator’s budget of approximately \$5,000,000 is excluded, the per-student cost is \$264. A figure that more accurately reflects the start-up costs for a school district to adopt this 2-year intervention can be calculated by adding the costs of workshops (including salaries for substitute teachers during workshops), local trainers’ time for on-site training, and instructional materials. Based on these expenses, the cost of providing math instructional materials and professional development for one pre-K or K teacher is estimated to be \$4,000 per classroom (\$1,500 for workshops and

\$2,500 for classroom visits every other week by a math specialist/local trainer for one year). At an enrollment of 20-30 students per classroom, this comes to \$133-\$200 per student for the initial year. There will be no expenses in subsequent years, other than replacing occasionally lost or damaged materials, or training new teachers when turnover occurs.

Assuming an enrollment of 20-30 pre-K or K students per classroom, start-up costs of \$4,000 per classroom, and using linear multipliers that assume no economies of scale, it would cost \$20,000,000 (5000 classrooms x \$4,000) to train 5,000 teachers and reach 100,000-150,000 students in a single year; \$50,000,000 to train 12,500 teachers and reach 250,000-375,000 students; and \$100,000,000 to train 25,000 teachers and reach 500,000-750,000 students. If economies of scale occur, costs will be lower.

**Justification for costs relative to expected benefits.** A proven and long accepted rationale for early education is that prevention is less expensive than later remediation. Economically disadvantaged children who attend public preschool programs are less likely to be referred for special education or to be retained in grade (Lazar & Darlington, 1982). We expect an early math intervention to provide similar benefits. To illustrate, students who enter and exit kindergarten below the 10<sup>th</sup> percentile at both time points, a large majority of whom are low-SES children, have a 70% chance of scoring below the 10<sup>th</sup> percentile five years later. Their mathematics achievement is 1 standard deviation below their peers who score above the 10<sup>th</sup> percentile in grade K. This difference grows to 2 standard deviations by grade 5 (Morgan, Farkas, & Wu, 2009). The likely outcomes for many of these students will be referral for special education in mathematics or grade retention (cf., Fletcher et al., 2007; Fuchs et al., 2007). Special education and/or grade retention are expensive alternatives to the early math intervention we propose.

**Use of the intervention beyond the grant period.** The California STEM Learning network will continue meeting with LEAs in Northern and Southern California quarterly (twice per region per year) to plan and discuss STEM education. This is expected to continue after the project ends and as long as the network's private funding permits. Our early math training

network, comprised of the PIs, regional and local trainers, will also participate in these meetings to ensure that early math education remains on the agenda for this group.

### **Significance and Magnitude of Effects**

Research clearly demonstrates that children from different sociocultural backgrounds enter elementary school at different levels of readiness for a standards-based mathematics curriculum (Clements, Sarama, & DiBiase, 2004; Klein & Starkey, 2004a; NRC, 2009; West, Denton, & Germino- Hausken, 2000). These achievement differences have their roots in early childhood (e.g., Ginsburg & Russell, 1981; Jordan, Huttenlocher, & Levine, 1994; Starkey & Klein, 1992). A recent cross-cultural study of children's early mathematical development in China and the United States found that cross-SES differences within each country are present at age 3 years (Starkey & Klein, 2008). However, the SES-related gap narrows in China during the preschool years but widens in the United States (see **Figures 2 and 3, Appendix J, pp J25-J26**). One contributing factor is that preschools in China implement a math curriculum for all children beginning at age 3, whereas most public preschool programs in the United States do not implement effective mathematics curricula. Thus, the SES-related gap in early mathematical knowledge has been developing for at least two years by the time low-income children enter kindergarten.

Additional evidence of the need for an early intervention comes from the literature on mathematical learning difficulties. Not only are mathematics difficulties as persistent as reading difficulties, but also the long-term consequences are just as severe. Long-term trajectories in mathematics achievement measured on children prior to formal school entry, and through the first few years of elementary school, clearly show that students who start poorly in mathematics continue to struggle in third and fourth grade (Bodovski & Farkas, 2007; Duncan et al., 2007; Duncan & Magnuson, 2011; Hanich, Jordan, Kaplin, & Dick, 2001; Morgan, Farkas, & Wu, 2009). In light of these considerations, a focused early mathematics intervention is needed, specifically an intervention that spans the preschool and kindergarten years of early childhood.

**Evidence of Intervention Impact** (also see **Appendix D**)

**Pre-Kindergarten component.** The developers of the pre-K component, *Pre-K Mathematics* (Klein & Starkey), have been the PIs on a number of Institute of Education Sciences- (IES-) funded experimental studies to test the impact of the pre-K intervention component. Randomized controlled trials were used in all the studies reported in **Appendix D** to control for threats to internal validity. The U.S. Department of Education's What Works Clearinghouse has assigned this intervention the highest rating of effectiveness (++) with the greatest extent of evidence (medium to large) for early math interventions. This intervention was also recently evaluated in a multi-state scale-up study, funded by IES, to determine whether it would be effective when implemented at the scale of an entire Head Start program or school district pre-K program. Effect sizes were .83 and .42, on the Child Math Assessment and TEMA-3, respectively, at the end of the pre-K year (Starkey et al., in press). The intervention, however, it did not completely close the SES math gap (see Figure 2 in **Appendix D**). The K component was developed to reduce this gap during the kindergarten year.

**Kindergarten component.** Two of the developers of *ELM* (Baker & Clarke) have been the PIs on a large experimental study to test the efficacy of ELM under rigorous conditions. An IES-funded randomized trial was conducted in randomly assigned K classrooms. All children participated in the study, but the analytical focus was on children who entered kindergarten at risk for mathematics difficulties. The Hedge's  $g$  effect size was .24 on the TEMA-3. Thus, ELM reduced the achievement gap during the course of the year (Clarke et al., 2011).

The combined effect of the two components of the intervention is expected to be greater than the effect for either component alone. Since the mathematical content of the two components has been aligned with only a small amount of overlap in each cluster of standards, we hypothesize that an additive effect will occur. This would elevate treatment children's math achievement by at least one standard deviation by the end of K.

In summary, both the pre-K and K components have been examined in rigorous evaluations and have been found to improve the math achievement of economically

disadvantaged students. In the proposed project, we seek to validate on a statewide level of scale the effectiveness of these components when combined together in a two-year math intervention in order to accelerate the mathematical growth of low-SES students and to prepare them for Common Core math standards of grade 1. Teacher reports of math achievement will be collected in grade 1.

### **Research Methods: A Randomized Experiment**

**Hypotheses and research questions.** Hypotheses and some research questions are generated from our theory of change. Other research questions are posed to guide analyses of the developmental relations among early and later competencies, such as K math knowledge and grade 1 reading and math achievement.

**Principal child outcomes.** We propose to validate the effectiveness of the pre-K and K components of an early math intervention when combined in a two-year treatment. The study also will examine whether the math intervention as implemented under realistic conditions on a statewide scale produces the expected achievement gains for high-need students in treatment schools. The hypotheses and research questions to be addressed are:

- (1) How does the pre-K component of the intervention affect mathematics achievement at the end of pre-K?
- (2) How does implementation of the pre-K and K components together affect mathematics achievement at the end of K?
- (3) How does implementation of the pre-K and K components together affect mathematics achievement at the end of grade 1?

**Impact on teacher math practices.** Does implementation of the math intervention have a proximal impact on the amount and breadth of math-related activities in the pre-K and K classrooms? Does implementation of the math intervention have an impact on classroom practices, in particular, the quality of teacher-student interactions involving math content?

***Mediation of causal influences.*** If significant differences are found between intervention and control classrooms on math-related classroom activities and practices, do these differences in classroom practices mediate children's math achievement?

***Moderation of treatment effects.*** Are treatment effects moderated by variables related to children, school, or other contextual factors? For example, does fidelity of implementation or dosage moderate impact? Does teacher experience or pedagogical content knowledge moderate impact? Do contextual variables, such as urban vs. rural settings or population demographics, moderate impact?

***Predictors of school achievement.*** Does children's mathematical knowledge in K, when enhanced through an effective two-year math intervention, result in better school achievement, in general, in grade 1? Does math knowledge in K predict later achievement better than reading, social skills, or self-regulation ability?

***Impacts on the SES-related gap in math achievement.*** To what degree does implementation of the two-year treatment close the SES-related gap in mathematical knowledge as measured by the math outcome measures (ECLS-B and K)? It should be noted that this is a secondary question to the primary impact and moderator questions.

**Participants: A consortium of local education agencies.** A consortium of LEAs, recruited through the California STEM Learning Network, has agreed to partner with WestEd and University of Oregon for the purpose of conducting the proposed validation project. The consortium includes urban and rural LEAs from Northern and Southern California (see letters of support, Appendix G). The school sample will provide diversity in location, type of preschool program (state-funded pre-K, Title 1, and Head Start classrooms), teacher background, and characteristics of the children and their families.

These LEAs collectively serve an ethnically and linguistically diverse population of low-income families: African-American (9%), Latino (30%), White (40%), Native American (2%), Asian-American (16%), and inter-racial/other ethnic groups (3%). English is the predominant language of classroom instruction in all programs. Predominant home languages include English

(70%), Spanish (30%), and others (1%). We estimate that approximately 30% of children in the consortium's pre-K classrooms will be monolingual Spanish speakers at the beginning of pre-K. However, based on prior research experience, most of these children will be bilingual (English-Spanish) speakers in math-related topics by the end of pre-K.

***Sample of schools, classrooms, and children.*** The research sample of schools will consist of 144 elementary schools with at least one pre-K classroom (state-funded pre-k, Head Start, or Title 1) and two kindergarten classrooms per school. The reason for selecting schools with this configuration was (1) to minimize child attrition, and (2) to prevent contamination across conditions during the transition from pre-K to K. In each school, half of the pre-K project children will be placed into each of the two K classrooms at random.

The statewide sample of schools will be comprised of schools from two regions of the state - 72 from Northern California and 72 from Southern California. Both urban and rural LEAs will be included. The intervention will be implemented over two years, with the first cohort of schools (N=72) beginning in school year 1 and the second cohort of schools (N=72) starting in school year 2. Each cohort will contain equal numbers of schools from the two regions. Rolling out the implementation across two cohorts of schools will be done for purely practical reasons. It will enable us to implement the project with a smaller staff and at a lower cost.

The child sample will be recruited and randomly selected at the beginning of children's pre-K year of school. Within each public pre-K classroom, all the 4-year-old children who are eligible on the basis of age to attend K the subsequent year, who are from low-income families, and for whom parental consent is obtained will be selected for the intent-to-treat research sample, up to 12 per classroom. LEAs indicate that most of the single age (4-year-old) and mixed age (3- to 4-year-old) classrooms will have at least 12 eligible children. Special needs children will be identified insofar as feasible and included in the sample if otherwise eligible. In cases where more than 12 children in a classroom are eligible for the research sample, a random selection will be made drawing equal numbers of boys and girls. All pre-K children will receive the math intervention in each classroom, but only those randomly selected will be assessed.

Thus, over two cohorts, there will be 144 pre-k classrooms, and at 12 children per classroom, a total sample of approximately 1,728 children.

Some attrition is anticipated during the pre-K year due to family circumstances such as a change of income level or relocation. In our recent studies, attrition was approximately 10%-12% from the pre-K to the K year. We expect lower attrition in the proposed study, however, due to the location of preschool classrooms on or near the elementary school sites. Children will be followed longitudinally through grade 1. Multiple tracking procedures will be utilized to maintain contact with participants. These include obtaining extensive parent and relative contact data at the beginning of the study, and updating this information by contacting parents twice per year as well as searching enrollment databases in nearby school districts. The sample that remains in the school district or neighboring districts will be assessed as needed to obtain a retention target of greater than 90% after the pre-K year and greater than 80% by the end of grade 1, with priority determined by geographical proximity.

### **Experimental Design**

The intervention effects of interest in this study are increases in mathematics achievement for high-need students at the end of pre-K, at the end of K, and then sustained through the end of grade 1. The study is an experimental design with two conditions, and schools (the unit of randomization) will be randomly assigned to one of the two conditions: (1) a treatment condition in which both the pre-K and K components of the intervention are implemented, and (2) a business-as-usual control condition, in which neither component of the math intervention is implemented. This design will allow us to answer questions about the effectiveness of the two-year intervention. Equal numbers of schools will be randomly assigned to the two conditions, with the constraint that equal numbers of urban/suburban schools, and equal numbers of rural schools, will be assigned to each condition within a given region (Northern or Southern) of California. At each school, the research sample of children will move from one pre-K classroom into two K classrooms. This will produce a balanced design in which there are 36 pre-K /72 K

classrooms and 432 children in each experimental condition in each region, as shown in Table 7 (**Appendix J, p. J27**).

Potential threats to internal validity will be addressed in the same manner as described above. In addition to use of an experimental design, random assignment at the school level protects against contamination of non-implementing control classrooms at the pre-K or K grade levels. A variety of child tracking procedures (see **Sample** above) will be used to minimize attrition, with the goal of keeping it below 20% from pre-K to grade 1. Potential threats to external validity will be controlled by including geographical diversity (multiple regions; rural and urban areas within California) with associated variation in classrooms, teachers, and characteristics of the children and their parents with regard to ethnicity, ELL status, and special needs. To maintain the full range of naturally occurring diversity in the study sample, no special selection of favorable schools, classrooms, or children will be allowed.

### **Training and Implementation Procedures**

The following section describes the training and implementation activities. A detailed timeline of these activities is given in Table 8 (**Appendix J, p. J28**). Also see the **Management Plan** for detail on how these training and implementation objectives will be met. Project activities will span part or all of 6 school years.

Training and implementation will begin for the 72 schools in Cohort 1 in 2013. After random assignment has been completed, trainers will be hired and pre-K teachers in schools assigned to the treatment condition will be notified about training activities. In spring of **2013**, we will conduct a trainers institute for local math trainers (see description in **Training for local trainers** below) as well as an introductory workshop for pre-K treatment teachers (see description in **Professional development of teachers and program monitoring** below). In the **2013-14** school year, we will focus on providing intensive training for pre-K treatment teachers through summer and winter workshops along with on-site training and implementation monitoring during the year. Treatment teachers will implement the pre-K math intervention from October to May according to a weekly curriculum plan (allowing for pretest and posttest

assessments of children). In addition, an introductory workshop will be conducted for K treatment teachers during spring of this school year. Then, in the **2014-15** school year, we will focus on providing intensive training for K treatment teachers through summer and winter workshops and on-site training and implementation monitoring during the year. Teachers will implement the K math intervention according to a weekly curriculum plan.

Training and implementation activities for the Cohort 2 schools will parallel what was done for Cohort 1, but they will be conducted one year later than for Cohort 1. They will commence with an introductory pre-K teacher workshop in spring of **2014**, followed by full implementation of the pre-K math intervention during the **2014-15** school year. Teachers at the control sites in both cohorts will continue with whatever professional development and instruction constitutes their usual practice. The nature and extent of control teachers' math practices will be documented through classroom observations. To maximize the benefits LEAs receive from participation in this project, the same training will be provided to control teachers in subsequent years after the research sample of children has left control classrooms.

**Training and monitoring of local trainers.** In order to implement our innovative pre-K and K math interventions at scale, we will first increase training capacity by establishing an early math network of local trainers in Northern and Southern California. Eight local early math trainers will be recruited and hired through official LEA partners using project funds. The local trainers will attend Early Math Trainers Institutes conducted by the PIs and statewide trainers on our staff. These institutes will enable local trainers to acquire early math expertise necessary to train teachers to implement the pre-K and K components of the intervention. Through the institute, local trainers will receive instruction and training in early mathematical development, early math milestones and standards, the pre-K and K components of the intervention, guidelines for, and supervised experience in, conducting math workshops and on-site training of teachers and implementation monitoring. This will include small-group management techniques, formative fidelity evaluation, progress monitoring in early math, helping parents support math at home, setting up math centers in classrooms, and other topics related to the intervention. Institute

time will include supervised on-site training sessions in local pre-K and K classrooms. Statewide trainers will monitor the quality of local trainers' on-site training by conducting monthly co-fidelity visits in which reliability checks of training are made (see Co-Fidelity Visitation Record, **Appendix J, p. J29**). Feedback and additional training will be provided as needed.

**Professional development of teachers and program implementation monitoring.**

Teachers will attend a sequence of multi-day workshops, including an introductory 1-day workshop in spring of the year before implementation will begin in their classroom. In the introductory workshop, teachers will be given an overview of activities in the specific math curriculum and will learn two representative math activities to practice with children who will not be in their classroom the following year. Teachers will participate in 3-day workshops in summer and winter of their first full year of implementation. These workshops are designed to ensure that teachers acquire knowledge of (a) relevant mathematics content, (b) milestones in early mathematical development, research findings on early SES-related math differences, and research demonstrating the effectiveness of our early math interventions, and (c) best practices in early childhood mathematics, including training in delivery of the pre-K or K component with fidelity and at sufficient levels of curriculum dosage for individual children, (d) small group and classroom management, (e) enriching math centers during the school year, and (f) working with parents to enrich the home learning environment. Teachers will also receive hands-on practice with math curriculum activities during these workshops, with feedback and support provided by the early math trainers.

After each workshop, teachers will implement math activities in their classrooms with on-site support and feedback provided by local trainers through bi-weekly visits. These formative implementation and fidelity observations will establish whether teachers are implementing all aspects of the intervention with fidelity, as scheduled, at the level of dosage needed for individual children, and with the use of progress monitoring (see fidelity instruments, **Appendix J, p. J30-32**).

**Data on program implementation, formative evaluation, and progress monitoring.**

Data will be collected to document implementation, formative evaluation, and progress monitoring by the teachers. Implementation of the program will be documented through collection of data on trainers' facilitation activities and on teachers' implementation activities. Data on training activities will include (1) information on teacher workshops (source: teacher workshop binders distributed to teachers; sign-in sheets completed at workshops), and (2) the frequency and quality of on-site facilitation provided to teachers (source: trainers logs; co-fidelity visit data collected from regional trainers). Data on teachers' implementation activities will include (1) teachers' records of dates that specific math activities were implemented and which children participated (curriculum dosage records), and (2) parent feedback forms that report use of each home math activity by individual families (see sample Parent Feedback Form, **Appendix J, p. J18**).

Formative evaluation data will be obtained in two ways. First, local trainers will keep records of their bi-weekly training visits to teachers' classrooms. They will check and record implementation of each component of the intervention expected from teachers, including classroom math activities and distribution of home math activities. Any type of formative feedback given will be recorded in their field notes (see fidelity instruments, **Appendix J, p. J30-32**). Evaluators will be provided a copy of each trainer's documents for each of their 16 teachers. Second, the evaluator also will directly evaluate fidelity during classroom observations three times per year. Data on teachers' use of progress monitoring will be collected from records kept by teachers.

**Management Plan****Plan for Achieving Project Objectives**

Table 9 (**Appendix J, pp. J33-J44**) presents details of the management plan. Also note that **Appendix J** contains detailed timelines for training and implementation activities (**Table 8, p. J28**) and data collection (**Table 10, p. J45**). We first provide an overview of the major project objectives across six school years from the beginning of the project in January, 2013 (midway

through the 2012-13 school year) to the end in December 2017. The shaded cells represent the implementation objectives related to the pre-K and K components for both Cohort 1 and Cohort 2 schools. The dark arrows illustrate the longitudinal nature of the study. Children will participate in their pre-K and K years in treatment or control classrooms (dark arrow).

Then, by school year, we list each major project objective and the key milestones and tasks associated with each objective, and the individuals responsible for each milestone and task. In school year 1 (2012-13) of the project, we will accomplish 3 major objectives: (a) Overall Study Preparation, (b) Pre-K Cohort 1 Preparation, and (c) Data Management System Preparation. Under these 3 objectives we will accomplish 10 milestones and 37 tasks. The milestones and tasks are related to site recruitment, instrumentation, project communication, PD for intervention implementation, training for data collection, and finalizing our data management system.

There are 5 major objectives in school year 2 (2013-14), a central objective being the implementation of component 1 of the intervention in pre-K Cohort 1 classrooms. The 19 milestones associated with this objective include collecting pretests and posttests with children, conducting fidelity observations, and intervention training and monitoring.

In school years 3 (2014-15) and 4 (2015-16), there are 6 objectives per year that primarily involve the preparing for implementation with one cohort, implementation with another cohort, and data collection. Expansion of the program within and beyond LEA partners will take place in school years 4 and 5 (2016-17). Final data analysis and reporting occur in year 5 and continue into the first half of school year 6 (2017-18).

**Management of evaluation activities.** Procedures for managing data collection are described above in the **Independent Summative Evaluation** section. As detailed below, Westat and the TWG members have extensive experience conducting large, complex projects.

### **Capacity to Bring the Intervention to a Statewide Scale and Sustain It**

**Scale of the project.** This project will be conducted at a statewide scale in California, and, within the state, in urban/suburban and rural schools in each of two large regions – Northern

and Southern California. By partnering with the statewide California STEM Learning network, which has been in existence since 2010, we will implement in diverse communities across California. This network is handling recruitment of school partners, subsequent dissemination of project findings, and meetings to foster a community of stakeholders to sustain the intervention during and after the grant ends. This and WestEd's intensive involvement in education in California, ensure that we have the capacity to take this effective math intervention to scale and to disseminate the program and its findings throughout the state.

This network has agreed to organize focused meetings with partner LEAs, in conjunction with general network meetings, to form a community of learners tasked with (1) implementing the two-year early math intervention and (2) developing and discussing procedures to foster sustainability (see the Network's letter in **Appendix B**). The PIs will bring their expertise in sustainability that was acquired in previous scale-up studies. An objective is to help LEA put procedures in place proactively to deal with sustainability challenges (e.g., providing training for new teachers when teacher turnover occurs). The network will also assist in recruitment of expansion schools (both within the current set of LEA partners and beyond) in the 2015-16 and 2016-17 school years. This expansion is intended to provide momentum for further dissemination of this innovative math intervention beyond the set of schools included in the main study.

**Development of an early math training network.** An objective of this project is to expand the training capacity in early mathematics in two regions in California – Northern and Southern California. The applicant partners have qualified personnel to conduct a project at the proposed scale. The WestEd PIs have already successfully conducted two federally funded, multi-state scale-up studies, the Oregon PIs have successfully conducted multi-state and statewide intervention projects, and the Westat PIs and Technical Working Group members all have extensive experience with large scale educational research projects (see **Qualifications of PIs and Key Personnel** section below). Furthermore, the primary grantee, WestEd, has

extensive management experience and organizational resources such as the unit housing the Regional Education Laboratory, REL-West, to administer a project at this scale.

Beginning with two existing nuclei of early math expertise comprised of the PIs at WestEd in California and at the University of Oregon and 4 regional trainers on our respective staffs, we will work with the consortium of school partners to recruit and hire approximately 8 more individuals with appropriate expertise and experience. Through the Early Math Trainers Institutes we conduct at WestEd, we will train these individuals to serve as local trainers/math resource specialists. Accordingly, these 8 local trainers, the 4 regional trainers on staff, and the 4 PIs will comprise a network of early math trainers for California.

Project funds will be used to create these 8 local trainer positions for the consortium of LEAs. A cooperative agreement will be drawn up to enable the trainers to work cooperatively such that trainers from neighboring areas can participate as trainers in workshops in other communities or counties. This cooperative feature of the network will be especially useful in rural areas and smaller cities, where LEAs face challenges that stem from their lower population density. One challenge is a need for a fraction of the time of one trainer. Our network model can accommodate this need by having a local trainer's time shared by multiple LEAs in a rural region of the state. When workshops are conducted, local trainers from elsewhere in the state can attend.

The early math network will be used to conduct a series of early workshops for groups of 18-36 pre-K or K teachers, depending on location, over the course of the project. A total of 144 pre-K and 288 K teachers from will receive professional development during the five years of the project. (432 teachers, @ 2 workshops per teacher, with an attendance of 18 to 36 teachers per workshop, equals 24-48 workshops over five years.) Three trainers are required for the smaller workshops; at six teams of three trainers, this comes to approximately 8 workshops per trainer over the 5-years of the project. Thus, we will have sufficient staffing to conduct the project at the proposed scale.

**Dissemination of the intervention and project findings.** After the validation project has been completed, our regional training network will be used to expand the intervention program in California. If the intervention is effective, we will also disseminate our project findings and the regional training network model, and offer training institutes in early math to other regions of the country. Dissemination will be accomplished through (1) empirical presentations of project findings and implementation experiences with LEA partners at national conferences, such as NCTM, that are attended by practitioners, administrators, or academic researchers, (2) use of WestEd's web- and print-based dissemination system, and (3) publications of project findings. We will also disseminate our model and findings within our region through personal contacts in order to sustain and expand the REM-West network after the project has been completed.

### **Qualifications of the PIs and Key Personnel**

The applicant partners have extensive experience implementing complex projects. Dr. Starkey and Dr. Klein of WestEd have successfully directed or co-directed two multi-state scale-up intervention projects (Starkey et al., in press; Sarama et al., 2007), as well as several other IES, NSF, and NIH funded projects involving intervention and data collection in preschool and elementary school settings in multiple countries and states (see CVs). Dr. Klein served for several years as PI for Elementary School Mathematics on the What Works Clearinghouse. Part of their record of intervention work that significantly improved student growth and achievement in mathematics is described above (see **Evidence of Intervention Impact**). Their IES-funded Preschool Curriculum Evaluation Research project involved implementing and rigorously evaluating a math intervention, *Pre-K Mathematics*, in public pre-K and Head Start programs in two states (California and New York). Implementation was successful and the intervention had longitudinal impacts on children's mathematics achievement in grades K and 1. Their training in developmental psychology (cognitive development), extensive experience in preschool and school settings, and experience directing and collaborating in complex early educational research and intervention projects makes them fully qualified to co-direct the project at WestEd.

Dr. Baker and Dr. Clarke of University of Oregon also have extensive experience implementing complex projects. They have successfully directed and collaborated on several multi-state intervention projects, including early math intervention projects funded by IES and NICHD (see CVs). Dr. Baker is also the Associate Director of the Center on Teaching and Learning and is PI on the Oregon Reading First grant, a 6-year implementation project involving 50 Oregon schools. Part of their record of intervention work that significantly improved student growth and achievement in mathematics is described above in **Evidence of Intervention Impact**. Their training and extensive experience in school settings, and experience directing and collaborating in complex early educational research and intervention projects makes them eminently qualified to co-direct the project at University of Oregon.

WestEd (with the Far West and Southwest Regional Labs beginning operations in 1966) has over 40 years of experience working with LEAs and schools across the country, and a strong track record of increasing student achievement, improving academic outcomes and closing achievement gaps through its work with LEAs and schools. WestEd's has extensive experience managing large, complex educational projects. Also see **Appendix D** for more information on the PIs' and WestEd's qualifications. See the **Evaluation Plan** (below) for qualifications of the evaluation team.

## **Evaluation Plan**

### **Measures**

Data will be collected in four primary areas and will include information derived from student outcome measures, classroom observations, teacher questionnaires and ratings, and parent feedback forms.

**Student outcome measures.** The principal math outcome measure will be the ECLS-B and ECLS-K mathematics assessments (USDE, 1998-99; Najarian, et al., 2010). The ECLS-B will be administered to the children in pre-K and K, and the ECLS-K will be administered in first grade. Items on the ECLS-B and ECLS-K mathematics instruments measure knowledge in the content areas of number sense, counting (preschool only), operations, geometry and spatial

sense, measurement, data analysis (kindergarten and first grade only), and patterns. Reliability (internal consistency) of the ECLS-B mathematics assessment is reported for the IRT-based scores and ranges from .89 for the preschool assessment to .92 for the kindergarten assessment. Theta reliability is reported at kindergarten/first grade and ranges from .92 - .94. Pre-k children who are Spanish-speaking with limited English proficiency will receive this mathematics assessment in Spanish and English, using bilingual assessors and conceptual scoring. The rationale for a bilingual assessment with conceptual scoring is that some children will acquire some math knowledge at home from Spanish-speaking parents and other math knowledge at school from English-speaking teachers. In addition, report cards of achievement in grade 1 will be collected.

Secondary measures, comprised of ECLS-B/ECLS-K Reading and Social Skills measures, will also be included to provide a set of measures comparable to those used by Duncan et al. (2007), and will be supplemented with self-regulation measures and supplemented by self-regulation measures, such as Day-Night Stroop, Yarn Tangle, and Gift Wrap tasks.

**Observation measures.** Two types of observation data will be collected three times per year. Implementation fidelity measures (specific to the *Pre-K and K components*) will be used to assess the adherence with which teachers implement each intervention component (see Fidelity of Implementation instruments in **Appendix J, p. J30-H32**). Generalized observation measures will also be collected in all classrooms in order to examine the effect of each component of the curricular intervention on math instructional practices (**Appendix J, p. J46**). The Early Mathematics Classroom Observation (EMCO; Starkey 2005) instrument will be used to measure the duration, nature, and conceptual breadth of the math activities provided by teachers to children in pre-K classrooms (**Appendix J, p. J47**). The Coding of Academic Teacher Student Interactions (CATS) instrument (Doabler et al., 2010) will be used in the K classrooms to systematically measure the instructional interactions that occur between teachers and students during kindergarten mathematics instruction. We will also administer teacher questionnaires to collect data on demographic variables such as education level as well as on their pedagogical

content knowledge of mathematics (Hill, Schilling, & Ball, 2004). In addition, pre-K and K teachers will provide ratings of their students' attention and inhibitory skills using the Children's Behavior Questionnaire (Rothbart et al, 2001). These measures will be used in moderator analyses. From parents, we will obtain information about the home math activities through a parent feedback form. **Table 10 (Appendix J, p. J45)** lists the measures and data collection timeline for the Main Study.

**Key elements and approach of project to facilitate replication and testing in other settings.** Data will be collected on aspects of implementation that should be followed by future efforts to replicate or extend this intervention research. The essential features of implementation include (1) the curriculum plan teachers follow, (2) the level of fidelity at which teachers implement the intervention, (3) the curriculum dosage levels delivered to children by teachers and parents, (4) use of progress monitoring (Math Mastery instrument), and (5) Pre-K and K math reports linked to Common Core math standards. As described above (see **Data on program implementation, formative evaluation, and progress monitoring**), high quality data will be collected directly on each of the above essential features of implementation through periodic classroom observations. Local trainers will also use these data formatively during implementation to monitor the quality of implementation. For example, record-keeping systems used as part of implementation will make it apparent to a trainer that a particular teacher has begun to fall behind in the curriculum plan; trainers will have been trained to assist teachers by providing feedback, discussing why the curriculum is being implemented slowly, and working with the teacher to solve this implementation challenge.

### **The Independent Summative Evaluation**

The independent summative evaluation will be conducted by Westat. PI Camilla Heid has extensive experience managing large-scale studies of pre-K and K education, and she will be responsible for data collection and quality control. A Technical Working Group, chaired by Co-PI Thomas D. Cook of Northwestern University, will be responsible for the study design, monitoring the evaluation, data analysis, and much of the report writing. The Technical Working

Group (see Key Personnel) that will provide expert input at critical points during the project. All decisions about hypotheses to test, schools to sample, data to collect, analyses to conduct, and interpretations to offer will be those of the TWG.

**Data collection.** Child assessments on math outcome measures will be conducted at five time points during the study: fall and spring of pre-K, fall and spring of Kindergarten, and spring of grade 1. Classroom observations of math practices and fidelity of implementation observations will be conducted three times in all pre-K classrooms and three times in all K classrooms for a total of 6 observation time points. Additional measures include ECLS-B/ECLS-K Reading and SRS assessments and a set of self-regulation measures for use at the same time points. The data collection will begin immediately following training of assessors and classroom observers for each wave of data collection. Assessors hired for this study will include a combination of English-speaking and English-Spanish bilingual staff who live near the sampled school districts. **Table 10 (Appendix J, p. J45)** shows the data collection timeline for the child assessment and classroom observation measures.

**Managing data collection.** Westat's Operations Director will have lead responsibility for coordinating the data collection plan and supervising the efforts of key individuals to ensure that all tasks are implemented in an efficient, organized and timely manner. The Operations Director will supervise the home office Field Managers, who are responsible for monitoring the day-to-day activities of the field assessment teams to ensure that data collection activities are completed efficiently and within the specified timeline.

**Scoring standardized tests.** The principal child outcome instruments include the ECLS-B pre-K and kindergarten math assessments, and the ECLS-K grade 1 math assessment. Westat will provide the data file for the ECLS-B and ECLS-K math assessments to the assessment developer, Educational Testing Service (ETS). ETS will score these and some secondary assessments, and provide the scoring for inclusion in the megafile to be produced annually by Westat. Research assistants supervised by Westat and the TWG will score self-regulation measures.

### Statistical Power Analysis

**Power.** Power of the design was determined using a Monte Carlo simulation wherein 1000 replications of the simulated experiment were analyzed using the design proposed. The simulation was based on several assumptions. First, previous experience has indicated typical effect sizes for the pre-K intervention of at least .40 standard deviations, so this value of effect was assumed for the pre-K intervention. Prior research with the K math intervention obtained effect sizes of about .25 standard deviations, and so this was used for the simulation. Our prior research also has yielded intraclass correlations of approximately .10, and this was built into the simulation at both the pre-K and K levels to reflect school level variance, which in this case is the same as classroom level variance, since there is only one pre-K and two K classrooms within each school. Normally distributed dependent variables with homogeneous variances were also assumed. Attrition was modeled at 6% per year and 6% between the pre-K and K years, for a total of 18%. Based on our prior experience with a similar population in similar settings, this is a conservative estimate. With less attrition, estimated power figures would be higher.

Then we generated 1000 simulated data sets having four time points with correlations between adjacent time points of .50 and effect sizes as mentioned. Then we analyzed each replication using a mixed model repeated measures analysis with subjects nested within their pre-K and K classrooms within each school, specifying time contrast for time 2 vs. time 1, time 4 vs. time 3, and time 4 vs. time 1. The model included variance components for both pre-K and K levels. The number of significant results in the 1000 replications was used as an estimate of the statistical power. The number of schools was varied, assuming 10 students per school; 36 schools per group yielded a power of .99+ for the comparison of time 4 to time 1 (effect size = .65), .95 for the comparison of time 2 to time 1 (effect size = .40) and .82 for the comparison of time 4 to time 3 (effect size of .25). If, as planned, 12 students per school are recruited, power will be higher. A total of 144 schools (2 conditions X 2 regions X 36 schools) are required to detect treatment effects within each region (Northern and Southern California) included in the study design.

## Hypotheses and Data Analysis

**General analytic technique.** All data will be examined for accuracy and for outliers prior to the tests of hypotheses. Outliers will be examined to determine if they are errors or just extreme data points. Errors will be corrected or listed as missing if correction is not possible. Extreme data points will be labeled and analyses done both with the extreme data in the model and out of the model so that it is possible to see the impact of such data on the results.

Since the data collected represents longitudinal and nested observations, we will use either linear or non-linear mixed models to analyze the specified hypotheses. Because observations are nested within subjects and subjects are nested within schools, the design is a three level design; however, level 1 is represented by the repeated measures. Examination of the distributions of the measured variables and the residuals from the mixed models will be examined to see if non-linear mixed models may be more appropriate for specific analyses. For example, in using the number of correct items on a test as a dependent variable, one often finds a positively skewed distribution of scores. Such data can be modeled using a Poisson or negative binomial distribution. These procedures can be applied using PROC GLIMMIX or NLMIXED software in SAS (SAS, 2010). Otherwise we will use SAS Proc MIXED software (SAS, 2010).

**Data analysis for principal child outcomes (Research Questions 1-3).** The purpose of this aim is to determine the impact of the two-year mathematics intervention implemented in pre-K and K classrooms on the math outcomes of low-income students in each region in California. The impact of the two-year intervention will be examined over time: (1) at the end of pre-K compared to the beginning of pre-K (to test Research Question 1), or (2) at the end of K compared to the beginning of K or the beginning of pre-K (to test Research Question 2).

This is a randomized control group design. Schools are randomly assigned to treatment or control conditions and one yoked pre-K and K classroom selected from each school for the study. The data are longitudinal, being collected at four points in time. Students are nested within schools. Because of the nature of the hypotheses, we will use a mixed model repeated measures analysis on this variable with specific contrast on the time variable to test the three hypotheses.

The comparison of the spring pre-K value to the fall pre-K will give the pre-K effect. The comparison of the spring K value to the fall K value will give the K effect, and the comparison of the spring K value to the fall pre-K value will give the total effect of the two-year intervention.

The purpose of this analysis is to determine the long-term impact of the mathematics intervention at the end of grade, one year following completion of the intervention. **Research Question 3** asks whether math scores will be higher for treatment students than for control students in spring of first grade. Because children will be nested within first grade classrooms, we will use a mixed models analysis, assuming that we have at least two students in most of the classrooms. If there are enough schools to estimate a separate variance component, we will do so. The TWG will plan and conduct analyses of longitudinal data to examine predictors of school achievement

Analyses of impacts on teacher math practices will focus on a set of best practices (greater use of small-group activities, focal activities, and scaffolding) we previously found were impacted by the type of professional development we will provide (Starkey et al., in press). Likewise, mediation analyses will be conducted, using bootstrapping, to determine whether causal influences of the curricular intervention are mediated by the above changes in teachers' mathematics practices. We previously obtained evidence supporting this hypothesis (Starkey et al., in press).

In a secondary analysis, we will use propensity score methodology (Guo & Fraser, 2009; Rosenbaum & Rubin, 1983) to compare the math performance of low-SES students in our sample with mid-SES students in the ECLS-B and K samples (Cook & Steiner, 2010). This analysis will be used to estimate a presumed standard level of performance of mid-SES children that is not available in our pre-K sample. This analysis is not intended to make causal inferences about performance of intervention impact. The groups will be matched on a number of covariates related to SES, and performance will be compared on the ECLS-B and ECLS-K math assessments. Details of the propensity score methodology for this secondary analysis are given in **Appendix J, p. J48**.

## **Qualifications of the Evaluation Team**

The independent evaluation is structured such that Co-PI Tom Cook will organize the Technical Working Group (TWG), which will monitor and direct Westat's evaluation, and conduct data analyses. Co-PI Heid of Westat will be responsible for all data collection, data cleaning, and preparation for analysis. The TWG is comprised of quantitative methodologists (Drs. Tom Cook and William Shadish), a statistician (Dr. Peter Steiner), a psychometrician (Dr. Donald Rock), a child poverty expert (Dr. Greg Duncan), and special education and math education expert (Dr. Russell Gersten). This is truly a stellar group with extensive expertise and experience of central relevance to the proposed project. Dr. Cook has served on several TWG for large federally funded evaluation projects, including Reading First, Advisory Committee on Head Start, and others (see CV). Co-PI Cook is an internationally esteemed quantitative methodologist, co-author (now with Dr. Shadish) of the standard text on experimental and quasi-experimental designs. Dr. Shadish is also an esteemed methodologist with considerable expertise in use of propensity scores (see CV). Dr. Rock is a prominent psychometrician whose many accomplishments at Educational Testing Service include authoring the psychometric report on the ECLS-K, which will be used in the current project (see CV). Dr. Greg Duncan is an expert on the impact of child poverty and has extensive knowledge of the ECLS data sets and measures. Dr. Gersten recently served on the National Mathematics Advisory Panel and has published multiple meta-analyses on early mathematical learning difficulties and disabilities (see CV). Dr. Steiner has advanced statistical expertise needed for data analyses in this project (see CV). He and Dr. Cook conducted the power analyses for this proposal.

Westat is one of the nation's premier research and evaluation organizations. The PIs for the evaluation, Dr. Heid and Dr. Cook, worked together successfully on the recently reported National Head Start Impact study, a large, longitudinal clinical trial evaluating the effectiveness of Head Start on several aspects of child development and school readiness. Thus, the evaluators have an extensive and successful track record conducting large and complex projects involving the assessment of children.