Approach to the Priorities

We have developed a tiered early math program, the *Pre-K Mathematics Tiered Instruction Program*. The components of the program are (1) a tier 1 mathematics curriculum, *Pre-K Mathematics*, (2) a tier 2 mathematics curriculum, *Pre-K Mathematics Tutorial*, and (3) a screening instrument, *Screener for Early Number Sense*, that identifies young children who are at risk for mathematical difficulties. The tier 1 and 2 curricula are closely aligned in mathematical content and use a small-group mode of delivery. The tier 1 curriculum and the tier 2 curriculum have been implemented apart from one another, and each was found to be effective. They have not been implemented together in the same classrooms, however, so their effectiveness when implemented in synergy has not been evaluated. The principal purpose of our Mid-phase proposal is to rigorously evaluate the effectiveness of the tiered instruction program when the tier 2 curriculum is implemented in classrooms that are also implementing the tier 1 curriculum. The effects of interest are math outcomes and school readiness status of children identified as at-risk for mathematical learning difficulties at the beginning of Pre-K. This proposal fits the criteria for a Mid-phase grant because the curricula are already fully developed, and the tier 2 curriculum will be evaluated in a new setting – in classrooms that are implementing an effective and aligned tier 1 curriculum rather than an ineffective and unaligned tier 1 curriculum.

Absolute Priority 1. Moderate Evidence

The **Evidence Form** details the quality and strength of evidence for the tier 1 and tier 2 interventions in the tiered early math program. The conclusion drawn in the Evidence Form is that the criteria for meeting Absolute Priority1 have been met.

Absolute priority 3. Field-Initiated Interventions - Promoting Equity in Student Access to Educational Resources and Opportunities (STEM)

Our tiered early mathematics program was developed by PIs [redacted] and [redacted] and is the first tiered early mathematics program to be developed and to undergo rigorous evaluation. It will provide children from low-income families with access to a mathematically rich learning environment at home and in their Pre-K classrooms. Educational resources include mathematics materials used by children and their parents at home and by children and their teachers in the classroom during guided mathematics activities. The home materials and activities used by families at home promote equity in low-income children's access to educational resources that are often missing due to the limited resources of low-income families. The mathematically rich learning environments we will provide for children at home and in their Pre-K classrooms will give low-income children opportunities for mathematics learning that they would not otherwise have. Also, our mathematics program is intended to enable children to enter elementary school ready to learn mathematics aligned with rigorous standards such as the Common Core State Standards for Mathematics or other rigorous state standards, rather than being identified as needing special instruction or simply falling further behind. Thus, our intervention is an important first step designed to give low-income children access to rigorous K-12 mathematics curricula. If low-SES children enter kindergarten unprepared for these rigorous standards, they will not truly have an opportunity to learn mathematics at the pace required by rigorous standards.

Competitive Preference Priority 1. Equity and Adequacy in Educational Opportunity and Outcomes

The SES gap in early mathematical knowledge forecloses, to a degree, important educational opportunities for low-SES children. As described in the Significance section, many low-income children who enter elementary school behind their more affluent peers remain behind, often falling further behind as they move to higher grade levels. This is highly problematic, because American K-12 mathematics education is attempting to provide mathematics instruction that is aligned with rigorous K-12 mathematics standards. When students fall too far behind in a standards-based mathematics program, they essentially lose the opportunity to reap the full benefits of this program. The outcomes of a rigorous K-12 mathematics program are preparation for entry into college, graduate school, and many professional programs and "math-heavy" STEM occupations (e.g., science and engineering) and STEM-related occupations (e.g., accounting and finance). If low-SES children enter kindergarten unprepared for these rigorous standards, they will not truly have an opportunity to begin learning mathematics at the pace required by rigorous standards.

A student-centered learning model is a cornerstone of our tiered early mathematics program. Teachers and tutors will be taught to implement classroom math activities in small-group settings and to provide developmental adjustments- individualized scaffolding, downward (less-challenging) extensions for children who are not ready for the initial (easiest) part of an activity, and upward (more-challenging) extensions for children who complete an activity with relative ease. Teachers and tutors will learn to use web-based educational technology on a tablet to monitor children's mastery of curricular content. Teachers' and tutors' pedagogical goal, viewed in the framework of sociocultural theory, will be to help children progress from adult-scaffolded (interpsychological) problem solving to independent (intrapsychological) problem solving (e.g., Lantolf & Poehner, 2014; Lantolf, et al., 2015).

The classroom mathematics activities are designed to be sensitive to the developmental needs of individual children. Suggestions are provided for scaffolding children who need help with a part of an activity. Finally, an Assessment Record Sheet, specific to the activity, was provided for teachers or tutors to keep a record of the progress of individual children during the activity. Curriculum plans provide time (e.g., review days or weeks) for teachers and tutors to review an activity with children who have been absent or who experience difficulty with it.

Competitive Preference Priority 2. Addressing the Impact of Covid-19 on Pre-K to Grade 12 Education

The Covid-19 pandemic has resulted in a loss of learning opportunities for young children. Enrollment rates for 3- to 4-year-olds fell 13 percentage points (from 54% to 40%) from 2019 to 2020 (NCES, 2022). Other impacts include lower rates of identification of children with disabilities and children at-risk for learning difficulties, higher rates of socio-emotional and behavioral challenges, and a decrease in home support for early literacy and numeracy (Barnett & Jung, 2021). Impacts appear to be greater for younger students, minority, and high-need students, and in math (Domingue et al., 2021; Donnelly & Patrinos, 2021; Dorn, et al., 2020). Kuhfeld et al. (2020) found that math scores of elementary school students dropped 5-10 percentile points.

In our EIR Expansion-phase project ([redacted] et al., 2018), the pandemic presented us with a natural experiment in which to test whether high-need Pre-K children are experiencing learning loss in math. At the beginning of the 2019-20 school year, prior to the onset of the pandemic in the United States, a cohort (Cohort 1a) of high-need 4-year-olds was assessed at pretest on the Child Math Assessment (CMA). In winter/spring of that school year the pandemic began, and early childhood programs suddenly closed. Consequently, this cohort of children could not be assessed at posttest at the end of the school year. In the 2021-22 school year, several of these programs re-opened for in-person instruction. A new cohort (Cohort 1b) of high-need 4-year-olds were assessed at pretest on the CMA. We compared the CMA scores of the two cohorts of children from the same early childhood programs. Pretest scores of Cohort 1b children were 7.5% lower than scores of Cohort 1a children, a difference that was statistically significant, $t\,(759) = 2.13$, $p<.05$. Cohort 1b children appear to have experienced learning loss in mathematics, arguably due to a loss in learning opportunities during the pandemic. Consequently, high-need children are entering preschool with less mathematical knowledge than before the pandemic. This lower knowledge level places more of them at-risk for learning difficulties in mathematics, and therefor in need of intensive tier 2 mathematics instruction. This problem is exacerbated by the widespread challenges early childhood programs are experiencing with staffing turnover and shortages caused by the pandemic (NAEYC, 2021). There is a need for in-service professional development in mathematics teaching for early childhood teachers, and there is a need for tiered early math curricula that teachers can use to prepare children for elementary school mathematics. Our project will address this need.

Significance

National Significance of This Project

Gaps (group differences) in mathematical knowledge begin to appear in early childhood. Early mathematics gaps have been revealed through cross-national (e.g., Miller et al., 2005; [redacted] & [redacted] 2008) and cross-SES (e.g., Reardon & Portilla, 2016; [redacted] et al., 2004) comparisons. These differences appear to be the result of differential levels of support in young children's home and preschool learning environments. For example, the breadth and depth of mathematical concepts used in home learning activities vary (Blevins-Knabe et al., 2000; DeFlorio & Beliakoff, 2015; Elliott & Bachman, 2018. Also, public preschool programs for low-SES children have been found to be ineffective at supporting mathematics learning (e.g., U.S. Department of Health and Human Services, Administration for Children and Families, 2010). The two most widely used curricula in these programs are The Creative Curriculum and High/Scope, both of which have been evaluated and found to be ineffective in the area of mathematics in independent randomized controlled trials (Howard, 2015; Preschool Curriculum Evaluation Research Consortium, 2008).

At the end of pre-kindergarten (Pre-K), low-SES children are almost one year behind their middle- class peers in math knowledge, a large difference at such an early age ([redacted] & [redacted], 2008). The math gap in grade K between children in the lowest and highest quintiles of SES is estimated at 1.3 standard deviations (ECLS-K math measure; Duncan & Magnuson, 2011; Duncan & Sojourner, 2013). A large percentage of children who enter and exit kindergarten with low math knowledge have math disabilities by 5th grade (Morgan, Farkas, & Wu, 2009) making early interventions promising for preventing or attenuating learning difficulties. Left unaddressed, the early math gap persists and increases as children move through school (Lee, Grigg, & Dion, 2007; Morgan, Farkas, & Wu, 2011; Rathbun & West, 2004). Large student gaps also make implementation of world class mathematics standards, such as the Common Core State Standards for Mathematics (CCSSM) or rigorous state-specific standards, an ongoing and expensive challenge at grade K and beyond, affecting the quality and/or the amount of time and costs associated with instructing students who lag far behind their peers, including increased child needs assessments, tier 2 or tier 3 instruction, and grade retention. Thus, there is a national need to address math gaps in young children.

Several math interventions have been developed to address SES-related math gaps in Pre-K children (e.g., Casey, Kersh, & Young, 2004; Clements & Sarama, 2007; Greenes, Ginsburg, & Balfanz, 2004). These interventions are essentially tier 1 classroom curricula developed for use with the general population of Pre-K children, including low-SES children, to prepare them for school mathematics. Few have been rigorously evaluated and found to be effective. *Pre-K Mathematics* ([redacted] & [redacted] 2004), however, is a tier 1 curricular intervention that has been rigorously evaluated and found to significantly improve low-SES Pre-K children's mathematical knowledge (see **Evidence Form**). In two recent studies we have found that, the gains children make in Pre-K were maintained in K when treatment children received a mathematics curriculum aligned with demanding Common Core math standards ([redacted] et al, 2022; [redacted] et al., 2018). In the latter study, children who received the Pre-K Mathematics intervention scored at the national average in math at the end of grade K ([redacted] et al., 2018).

Despite the effectiveness of this curricular intervention for low-SES Pre-K children in general, there is a subgroup of children who receive the intervention but continue to show low growth in mathematics over the Pre-K. For example, in a recent i3 statewide validation study ([redacted] et al, 2018; [redacted] et al, 2018), despite significant positive treatment effects for *Pre-K Mathematics*, 19% of treatment children were still below the 25th percentile, and 9% were even below 10th percentile, on the TEMA at the end of the Pre-K year. Thus, there appears to be a subset of young children who are at risk for math difficulties.

These findings are consistent with those for school-age children showing that Tier 1 classroom instruction, although effective for many children, is not effective for a subset of children. In particular, the duration and intensity of instruction are insufficient for these children (Fletcher, Lyon, Fuchs, & Barnes, 2007). Failure to address the special learning needs of young children who struggle with mathematics has important educational consequences. Long-term trajectories in math achievement measured on children prior to school entry, and through the first few years of elementary school, show that children who start low in mathematics continue to struggle in third and fourth grade (Bodovski & Farkas, 2007; Duncan et al., 2007; Jordan, Kaplan, Olah & Locuniak, 2006; Morgan, Farkas, &

Wu, 2009). For children with severe math difficulties, the consequences are particularly dire. For example, children entering and exiting kindergarten below the 10th percentile at both time points, a large majority of whom are children from low-income backgrounds, have a 70% chance of scoring below the 10th percentile five years later. Their math achievement is 1 standard deviation below their peers who scored above the 10th percentile in grade K. This difference grows to 2 standard deviations by grade 5 (Morgan et al., 2009). Furthermore, of children identified with a math disability in grade 5, 95% remain in the lowest 25% of children in math in grade 11 (Shalev, Manor, & Gross-Tsur, 2005). We conclude that even if an effective tier 1 curricular intervention like *Pre-K Mathematics* is used in public Pre-K classrooms, a need remains to provide more intensive tier 2 intervention for a subset of Pre-K children who are at risk for learning difficulties in mathematics.

Recent research has also shown that the need for intensive instruction may be growing, and it may be especially beneficial for some groups of children. First, as noted above in the section on Competitive Preference Priority 2, evidence exists of early learning loss in mathematics due to the Covid-19 pandemic. Intensive tier 2 instruction could be used to reverse this loss. Second, the situation that many Native American children face in the initial grades of elementary school suggests that intensive tier 2 math instruction could be especially beneficial. Analysis of data from a very large national study found that approximately 15% of Native American children are referred for special education in elementary school, more than other demographic groups. The strongest predictor of placement was school readiness status in math and literacy at the beginning of K (Hibel, Faircloth, & Farkas, 2008). Tier 2 math instruction could be used to improve the school readiness status of Native American children and thereby reduce special education referrals. We will over sample Native American children in our project to make it possible to conduct a sub-group analysis to determine whether tiered instruction is beneficial for them specifically.

The Promising New Educational Strategy: The *Pre-K Mathematics Tiered Instruction* program

Tiered math instruction has been used successfully in the elementary grades (Fuchs et al., 2021) but is yet to be utilized in Pre-K. As described earlier, math intervention research in Pre-K has been concerned with developing and evaluating tier 1 curricular interventions. The proposed project builds on this work but extends it considerably by implementing an intensive tier 2 math intervention as well as effective tier 1 intervention in the same classrooms.

We will implement the *Pre-K Mathematics Tiered Instruction* program. This is a tiered early math program that includes (1) a tier 1 curricular intervention, *Pre-K Mathematics*, for the general population of low-SES children in public Pre-K programs, (2) a tier 2 curricular intervention, *Pre-K Mathematics Tutorial*, for Pre-K children who are risk for mathematical learning difficulties, and (3) a screening tool, the *Screener for Early Number Sense,* to identify Pre-K children who are at risk for mathematical learning difficulties. Evidence of effectiveness for the tier 1 and tier 2 curricula is given in the **Evidence Form**

Thus, our tiered early math program is an innovative educational strategy. It holds promise for improving mathematics achievement, especially for children from low-income families and children from all levels of SES who are at risk for mathematical difficulties.

Potential Contribution of the Proposed Project to Mathematics Education and School Readiness

The proposed project will contribute in multiple ways to knowledge and understanding in the field of early education intervention. First, in education sciences the proposed project has the potential to advance the field of early intervention by testing the combined impacts of tiered early math instruction on a large segment of the child population attending public Pre-K programs, including low-SES children who are behind their middle-SES peers in math but not at-risk for learning difficulties in math and children who are at-risk. A finding - that the educational strategy of early tiered instruction is effective at reducing the early SES-related math gap such that a large majority of children enter grade K ready for standards-based math instruction and not at risk for learning difficulties in math – will expand the early intervention knowledge base. It may also be seminal in that it could stimulate further research on early tiered instruction in developmental domains other that math (e.g., language, emergent literacy, or executive functioning). This finding would also inform public Pre-K education policy and practice regarding the potential benefits of early tiered instruction.

Second, a base of scientific knowledge already shows close and complex developmental relations between the attention system and mathematical cognition (E.g., Cueli et al., 2020; Peterson, et al., 2017). The proposed project will add to this base by examining potential moderating influences that general cognitive domains (the attention system and working memory) might have on specific cognitive domains (mathematics) (see logic model, Appendix G). Third, knowledge will be acquired about the extent to which early pandemic-related learning loss can be reversed in Pre-K. And fourth, we will learn whether early tiered math instruction has the potential to reduce referral rates of Native American children for special education.

Strategy to Scale

Barriers that Impede Scaling, and Strategies to Mitigate or Remove Them

The adoption of curriculum guidelines and standards that include mathematics for public preschool programs represent a demand by federal and state policy makers and early education administrators for effective math support. Local programs are expected to utilize curriculum and instructional practices that prepare children from low-SES backgrounds for elementary school mathematics. Improving low SES children's math outcomes, however, has proved to be difficult for programs to achieve. Federal strategies have included requirements for Head Start programs to increase the percentage of teachers with a BA degree. Research, however, has cast doubt on the sufficiency of this approach to produce effective Pre-K teachers in academic areas such as emergent literacy and math (e.g., Early, et al., 2007). A strategy that has been tried by state preschool programs is to use quality rating improvement systems (QRIS) to improve program elements, such as teacher-child interactions, the general program environment, and administrator qualifications. QRIS validation studies have obtained little evidence that ratings predict (i.e., are correlated with) child development and school readiness outcomes, and they provide no evidence that the improvements made are causally related to improved child outcomes. It is noteworthy that none of the QRIS efforts included evidence-based curricula among the improvements that were tested (Karoly, 2014; American Institutes for Research (AIR) & RAND Corporation, 2016). The development of effective tier I math intervention, such as *Pre-K Mathematics*, have proved to be a better strategy for providing effective math support.

Intervention research, however, has found that even when a generally effective tier 1 math intervention is used in public preschool programs, mathematical learning by a subset (estimated above as 19%) of children is not sufficient for them to be ready for grade K mathematics. Building on the strategy of tiered instruction used in elementary school mathematics, we hypothesize that many of these children would benefit from a program of tiered early math instruction. Why is such a program not already in place in public early childhood programs? Use of tiered instruction is a new educational strategy for public early childhood programs. There are two principal barriers that currently prevent the use of tiered early math instruction in the Western/Southwestern region.

Barrier 1

Federal and state public preschool program staff have insufficient professional preparation to implement a tiered early math program effectively. Early childhood professional development staff will need to be trained before they are able to provide professional development needed for Pre-K teachers to implement this strategy effectively.

Strategy 1.1. Train the trainers to provide PD for implementing the tiered early math program. We propose to use trainers in WestEd's national network of early math trainers, specifically trainers in the Western/Southwestern region. Project leadership ([redacted]) will provide training in tiered instruction to the regional trainers during the initial preparatory year of the project. Next, they and the regional trainers will plan and conduct a 3-day trainer-of-trainers' institute, the *Pre-K Mathematics Tiered Instruction* institute. The institute will provide training and certification in tiered math curriculum coaching for LEA staff who provide professional development (PD) to early childhood instructional staff. A WestEd regional trainer will certify each coach in the institute (tier1 and tier 2 curriculum certification; see **Appendix J, p. J20**) and through two co-fidelity visits in program classrooms and designated tutoring locations (fidelity certification). The tier 1 content of institute has already been developed and used in our EIR Expansion-phase project. Our *Pre-K Mathematics* (tier 1) institute includes information on early mathematical development in children, grade K math standards, the scope and sequence of Pre-K Mathematics, hands-on practice with selected classroom and home math activities, implementation data collection and monitoring procedures, fidelity support visits for teachers, and classroom management techniques (see **Appendix J, pp. J6-J28** for additional detail). Tier 2 and screening content, however, will be added to the institute. The new content will include information on early mathematical learning difficulties, on mathematical disabilities (e.g., dyscalculia), and longitudinal achievement challenges when left unaddressed, the scope and sequence of the *PKMT* curriculum, hands-on practice of selected tutorial math activities, and fidelity support visits for tutors, and information about the purpose of early math screening, and an introduction to the SENS and how it will be used. The objective is to enable early childhood professional development staff employed by school districts and Head Start programs in the region to understand and support the tiered early math program that will be implemented in their LEA. The institute will be followed by co-fidelity visits by coaches and a WestEd regional trainer in program classrooms and tutoring locations at the beginning of implementation and subsequently to provide on-site training to coaches to ensure that they can monitor and support teachers'/tutors' implementation. During these visits, fidelity checks of coaching will be made by the WestEd trainer, and fidelity checks of teachers/tutors will be made by coaches and the WestEd trainer, with feedback provided as needed (also see **Goals, Objectives, and Outcomes** section in **Project Design** below).

Strategy 1.2. Train the teachers and tutors to implement the tier 1 and tier 2 curricula, respectively. The Project Director, PIs, and regional trainers will plan, and regional trainers and coaches will conduct, workshops and on-site coaching for Pre-K teachers. Regional trainers will conduct separate 4-day workshops for tutors at the beginning of the school year. and on-site coaching will be provided for tutors. Workshops and coaching will enable teachers and tutors to implement the tiered early math program with adequate fidelity and curriculum dosage (see **Timeline for Training and Implementation Activities, Appendix J, p. J3**). As was the case for the trainers' institute, the tier 1 content of the teacher workshop has already been developed and used in our EIR Expansion-phase project. Tier 2 and screening content, however, will be added. Teachers will participate in 6 days of workshops (3 at the beginning of the school year and 3 midyear). Tutors will participate in 4 days of workshops. Workshops will provide teachers and tutors with professional training in (1) the tier 1 curricula (for teachers) or tier 2 curricula (for tutors), including scope and sequence, demonstrations of math activities, explanation of math content, discussion of practices found to be effective, and hands-on practice by teachers in groups using the activities, (2) use of iPads to collect implementation data, including authentic assessment of children's performance on each math activity (Assessment Record Sheet), progress monitoring (Math Mastery), and classroom and home dosage records (Parent Feedback Form), (4) the home math activities and parent outreach procedures (teacher workshop only), (5) mathematical enrichment of the classroom learning environment periodically throughout the school year (teacher workshop only), (7) early mathematical development, including research demonstrating an SES gap in early math development and the positive effects of early intervention on early mathematics achievement (teacher workshop only), (8) information on early mathematical learning difficulties, on mathematical disabilities (e.g., dyscalculia), and longitudinal achievement challenges when left unaddressed, (8) early math milestones and standards (e.g., Head Start's Mathematics Development Domain; Common Core State Standards for Mathematics for kindergarten) (teacher workshop only), (9) using pedagogical content knowledge to decide when and how to make developmental adjustments during math instruction, (9) small-group and classroom management techniques (content differs for teacher and tutor workshops), (10) supporting EL children, (11) personalizing children's learning, (12) the purpose of having local trainers conduct classroom or tutoring session visits during implementation.

Teacher workshops will be followed by 8-10 in-classroom fidelity support visits, depending on need, with visits concentrated more heavily in the first half of the school year but occurring across the year. Tutor workshops will be followed by 6 on-site fidelity support visits by coaches (initially with regional trainers), distributed similarly to in-classroom visits for teachers. The curriculum coach (and periodically a WestEd regional trainer) will make fidelity support visits. These visits will take place during actual implementation of *Pre-K Mathematics* or *PKMT* activities, and formative feedback will be provided to ensure that teachers and tutors implement the tier 1 and tier 2 curricula with fidelity, as scheduled, at the recommended level of dosage, and using progress monitoring.

Barrier 2

There is insufficient evidence about the efficacy of tiered early math instruction. Education policy makers and public preschool programs need scientific evidence to make data-driven decisions about utilizing a tiered early math program. The efficacy of our tiered early math program needs to be rigorously evaluated in a RCT.

Strategy 2.1. Teachers and tutors implement. LEAs will implement the tiered early math program using a curriculum plan to deliver scripted *Pre-K Mathematics* and *Pre-K mathematics Tutorial* activities, respectively, with fidelity and adequate curriculum dosage. Implementation will be monitored through fidelity supports visits, as described above, and through the collection of real-time implementation data by coaches, teachers, and tutors on iPads using cloud-based software and data storage (see **Management Plan and Procedures** and **Evaluation Plan**, **Implementation Metrics and Thresholds** for more information.

Strategy 2.2. Children's math learning is assessed. High-need children, including children identified as at-risk for mathematical learning difficulties, will receive tiered math instruction; their peers in control classrooms will not. Children will be assessed at the beginning and end of the school year to provide evidence of growth of mathematical knowledge, and they will be screened to determine whether their risk status for mathematical learning difficulties changes from the beginning of Pre-K to the beginning of K. Additional data will be collected on possible moderators and mediators as described in the **Evaluation Plan**; also see **Measures and Data Collection Timeline, Appendix J, p. J4-J5**. See **Key Project Components, Mediators, Outcomes, and Implementation Metrics** in the **Evaluation Plan** for information on assessment of children's math learning.

In summary, these strategies address important barriers that impede the use of tiered early math instruction. The proposed strategies will mitigate or remove these barriers and therefore facilitate use of tiered early math instruction by local early childhood programs.

Management Plan to Achieve Project Objectives

In general, we utilize overlapping teams who (1) focus on specific aspects of the national project such as teacher workshops, (2) hold regularly scheduled team meetings with agendas, (3) establish clear responsibilities for team members, and (4) use timelines with intermediate task-completion dates ("milestones"). Most meetings are held virtually to accommodate staff in other states or different parts of California, and to be efficient. Over the past few years, we have shifted from paper forms to digital ones for the collection of implementation data. Curriculum coaches, teachers, and tutors are provided a tablet (iPad) that is used to access a web-based platform. This has made it possible to collect implementation data that are valid, timely, and accessible to those who need to use it formatively. For example, curriculum coaches input data from classroom fidelity visits, and teachers use the iPad to input children's dosage and performance on math activities as they are conducting them. Progress monitoring (Math Mastery) is processed electronically and presented to teachers in real time. Our national staff have access to the same data and can track implementation daily by teachers with individual children. One of our teams meets weekly to examine and discuss ongoing implementation. Thus, we are able to closely monitor several types of project activities.

To illustrate our management plan for this project, we will focus on the four principal objectives that are associated with the four strategies listed above. These objectives, a series of tasks (milestones) necessary to meet the objectives, responsible personnel, and timelines for carrying them out for Cohort 1 are detailed in a table (see **Management Plan, Appendix J, p. J2)**. Most of these objectives and tasks will recur in Cohorts 2 and 3 as new LEAs begin using the tiered early math program.

Collection of Child Outcome Data in the Field

The Independent Evaluator at University of Nevada, Reno will employ careful procedures to ensure that child data are collected accurately and as scheduled. For example, quality control checks of data will be made, both in the field and redundantly at their offices, early in each wave of data collection and for each data collector. The evaluator will employ careful procedures to ensure that child data are collected accurately and as scheduled. For example, quality control checks of data will be made, both in the field and redundantly at their headquarters, early in each wave of data collection and for each data collector. Finally, a research associate and Co-PI [redacted] will meet with the external evaluator regularly (weekly to monthly, depending on the phase of the project) to ensure that project objectives and milestones are being met on schedule.

WestEd's Capacity to Conduct the Project on a Regional Scale

We are experienced and extremely well-positioned to conduct an EIR Mid-Phase project at a multi-state, regional level. Our team at WestEd, including senior staff, Pre-K trainers, and research assistants, and the external evaluation team have collaborated on a successfully executed project implemented at a state level of scale ([redacted]; [redacted]) and on EIR Expansion-phase project implemented at a national level of scale ([redacted]). Our management capabilities are strong, as evidenced by the latter project, which has largely been conducted during the pandemic. We have established and maintained partnerships with many LEAs in the West/Southwest region and elsewhere, and consequently, have a deep understanding of the operations, organization, staffing, and challenges of LEAs and their early childhood programs.

Project Leadership and Regional Center Team

[redacted] of WestEd (see CV, Appendix B), will serve as the Project Director (PD) and will oversee the project, including monitoring the activities of the West/Southwest Regional Training Center. Trainers from this center will train LEA coaches and teachers in the proposed project.

[redacted], along with Co-Principal Investigator (Co-PI) [redacted] (see below), has successfully directed or co-directed two multi-state intervention projects ([redacted] et al., 2008; [redacted] et al., 2014), an i3 validation study on a statewide scale, an EIR expansion project on a national scale, an IES tiered-instruction project and several other IES, NSF, and NIH funded projects involving intervention and data collection in preschool and elementary school settings in multiple states and countries. Co-PI [redacted] of WestEd (see CV) has a Ph.D. in special education and will oversee training of tier 2 tutors for the proposed project. [redacted] served as the Statewide Trainer for WestEd's i3 validation study ([redacted] 2012) and has over 15 years of experience working on large-scale federally funded efficacy studies, overseeing the implementation and fidelity of early educational interventions. [redacted] will lead work at the regional training center, attend and oversee train-the trainer institutes and teacher/tutor workshops and will monitor the overall implementation of the *Pre-K Mathematics Tiered Instruction Program*. The PD and Co-PIs will monitor collection of implementation data through weekly meetings with project staff. [redacted] of WestEd (see CV) will serve as PI and will coordinate and monitor the agencies comprising the external evaluation team (see below). [redacted] has led or co-led several federally funded projects with [redacted] referenced above. [redacted] also served for several years as PI for Elementary School Mathematics on the What Works Clearinghouse. She will serve as Evaluation Team Coordinator and will oversee evaluation activities and coordinate with the various agencies associated with the evaluation team. Specifically, she will be responsible for regular meetings with the PI at University of Nevada, Reno (UNR) in preparation for and during each wave of data collection. She will also work closely with UNR to ensure that data scoring proceeds in a timely manner and with [redacted] regarding data analysis. WestEd leads the U. S. Department of Education's Region 13 Comprehensive Center, which provides technical assistance to the Bureau of Indian Education. Leadership in this Center are serving as our thought partners on the sub-study of school readiness of Native American children.

Independent Evaluation Team

[redacted] of University of Nevada**,** (see CV) and [redacted] of Format Consulting LLC (see CV) will lead the evaluation. Both have extensive expeience with large research projects and have successfully partnered with WestEd team previously. She has worked closely with [redacted] on our two most recent projects and will plan and conduct data analysis and report impact findings.

WestEd's Capacity

WestEd is a Joint Powers Agency (JPA), authorized in 1995 by a California Joint Powers Agreement and governed by public entities in Arizona, California, Nevada, and Utah, with Board members representing agencies from these states and nationally. Its two predecessors, Far West Laboratory for Educational Research and Development (FWL) and Southwest Regional Laboratory (SWRL), were JPAs created in 1966. Since 2000, WestEd has carried out over 4,000 successful projects representing major contributions to the nation's R&D resources, and has from 450 to 700 active contracts and grants at any given time. Funding for specific projects comes from sources including the U.S. Department of Education (ED), National Science Foundation, and U.S. Department of Justice; state departments of education; and universities, school districts, foundations, and other state and local agencies across the country. The proposed project will be conducted within WestEd's STEM Program, which is conducting approximately two dozen large to medium scale research, development and technical assistance projects each year. In its capacity as a large educational research and development organization, WestEd provides the resources and support needed to ensure the success of projects and will provide necessary resources to ensure the success of this study. Highly developed management structures, including fiscal management, research quality control and review, personnel support, communications, technology, meeting spaces, and other resources are in place to ensure successful and timely completion of objectives.

Additional Considerations

The team of PIs have strong merit based on two important factors. First, we have a strong track record of securing research and development funds through i3, IES and other federal and state entities. We have developed and evaluated interventions through IES and other funding sources. Through this work, we have developed a replicable methodology for implementing rigorous development and research activities in actual field settings (i.e., schools and classrooms). Perhaps most important is the fact that across several projects, we have (1) developed interventions, (2) secured funding for efficacy and scale-up projects, (3) completed methodologically and pragmatically successful trials, and (4) reported our main child outcome findings in prestigious, peer-reviewed journals, such as *the Journal of Research on Educational Effectiveness* and *Child Development*. These considerations demonstrate our ability to conduct the project as proposed.

Plan for Disseminating Project Products and Findings at the Local and Regional Level

Project findings and products will be actively disseminated using multiple strategies. Our approach to "piggyback" on the dissemination procedures that staff in our national EIR Expansion-phase project are currently using.

Dissemination Strategy 1

We currently use direct contact to disseminate project findings and products to public preschool programs. Lists of local programs were obtained from regional associations and funding agencies. Direct contact is made with local Head Start and state preschool programs through an e-mail survey, with information provided in the e-mail and through a link to our landing page on WestEd's website. This is followed by phone calls to interested programs in which funding, training, and roll-out options are discussed. In our EIR Expansion-phase project, this strategy is being implemented in the regions served by the regional training centers. In the proposed .project, this strategy will focus on the Western/Southwestern region in which the project will be conducted.

Dissemination strategy 2.

A dissemination strategy targeting western/southwestern state, regional, and Bureau of Indian Education-affiliated stakeholders will be used after the main confirmatory findings have been obtained. WestEd newsletters will be sent to stakeholders. Also, curricular or empirical presentations will be made at state and regional practitioner conferences, such as the American Indian Indigenous Teacher Education Conference, the California Association for the Education of Young Children, and the Region 9 Head Start Association, and at national research and policy-oriented conferences, such as conferences held by the Council for Exceptional Children, the National Council of Teachers of Mathematics, and the Society for Research on Educational Effectiveness.

Project Design

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. Elsewhere we will detail our training, implementation procedures, implementation data collection, and quality control system.

The Early Development of Mathematical Cognition

The primary conceptual foundations of children's early mathematical knowledge include the cognitive domains of number and space. These domains are partly structured during infancy, and continus to develop during the preschool years and beyond, (e.g., Ginsburg, et al., 1998). 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. Children with more extensive informal mathematical knowledge in preschool tend to acquire formal mathematical knowledge earlier and more extensively in early elementary school. Low-SES preschool children, relative to their middle-class peers, possess less extensive informal mathematical knowledge. Early mathematical knowledge is constrained by a developmental niche 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. This knowledge develops primarily in, social activity settings – specifically, settings in which children are actively participating in concrete math activities with teachers or parents who scaffold their learning. Therefore, math instruction is most effective when children's teachers possess pedagogical content knowledge of early math.

Model of Causation

Our logic model is given in **Appendix G, Figures 1a-1c**. The active ingredients in the tier 1 (Figure 1b) and tier 2 (Figure 1c) curricular interventions are modeled as the mathematics content from Pre-K Mathematics and Pre-K Mathematics Tutorial. Intensive and frequent PD will be the primary means through which teachers and tutors become able to deliver the curricula with both fidelity and understanding (cf., Shulman, 2000). The in-depth, domain-specific PD support that teachers and tutors will receive – math focused workshops and on-site training aligned with the mathematics - 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 recommended curriculum dosage, and (c) are able to support child engagement and learning of mathematics through explicit, teacher-guided instruction.

We expect that teaching essential mathematics content through effective small-group delivery techniques in school classroom and tutoring settings will change the nature of teaching and learning opportunities for children. Thus, we predict that the mathematics experiences of children will be different in treatment classrooms than in control classrooms, and we expect that the frequency and topography of the instructional interactions between teachers and children will be different in treatment classrooms relative to control classrooms. At tier 1, treatment children will spend more time than control children engaged in developmentally sensitive, teacher-scaffolded small-group mathematics activities. At tier 2 this will also be the case and treatment children will receive more intensive support, whereas control children will receive no tiered math instruction. Thus, all treatment children will spend more time than control children engaged in intentional small-group math activities and treatment children who are at risk will spend additional time in math activities that are appropriate for their current level of mathematical knowledge. Possible child-level moderators include two domain-general cognitive systems (attention and working memory) that cognitive developmental theory hypothesizes, and research finds in some respects, to be related to domain-specific mathematical development in children. Regarding child outcomes, we predict that (1) implementation of Pre-K Mathematics as intended will have a positive and direct causal effect on child math outcomes for the general population of low-SES children and (2) implementation of Pre-K Mathematics and Pre-K Mathematics Tutorial together (i.e., in a tiered program) as intended will have a positive and direct causal effect on child math outcomes for children identified as at risk for mathematical difficulties.

Principal project Goals, Objectives, Expected Outcomes, and Measures of Outcomes

The principal goals of this project are to remove the principal barriers that currently impede use of the Pre-K Mathematics Tiered Instruction program in the Western/Southwestern region. These goals and their associated strategies, project objectives, and performance measures are as follows.

Goal 1. Reduce or remove barriers consisting of public preschool program staff having insufficient professional preparation to implement a tiered early math program effectively. **Strategy 1.1**. Train the trainers to provide PD for implementing the tiered early math program. **Project Objective 1.1.** Completion of WestEd's training in the Pre-K Mathematics Tiered Instruction program and certification as curriculum coaches by 50 % of participating LEA professional development staff. (This assumes that programs will want half of their PD staff to receive this training, and that all who receive it will become certified.) **Performance Measure 1.1**: LEA PD staff who (1) complete the trainers' institute [measured by sign-in sheets: adequate attendance = 3 days], (2) pass staff certification [< 10% errors, scored by WestEd regional trainer] and (3) pass fidelity certification (< 10% errors in at least 1 co-fidelity visit with a WestEd trainer]. **Strategy 1.2.** Train the teachers to implement the tier 1 curriculum and tutors to implement the tier 2 curriculum. **Project Objective 1.2a**. All participating LEAs' teaching staff who instruct Pre-K children and who either are required by the LEA to participate or who volunteer to participate (depending on LEA administrative procedures) will become fully trained and capable of implementing *Pre-K Mathematics*. **Performance Measure 1.2a**: LEA teaching staff who (1) complete the teacher workshop [measured by sign-in sheets: adequate attendance = 6 days], (2) receive adequate curriculum coaching [incidence of coaching measured by a certified coach on iPad: adequate = 8-10. **Project Objective 1.2b**. WestEd will hire and train all tutors for the evaluation. All (100%) will be required to fully attend the tutor workshop and to receive 6 coaching visits. Fidelity and dosage delivery will be conducted by LEA coaches and WestEd staff. They will be required to become fully trained to implement *Pre-K Mathematics Tutorial*. **Performance Measure 1.2b**: Tutors who (1) complete the tutor workshop [measured by sign-in sheets: adequate attendance = 4 days], (2) receive adequate curriculum coaching [incidence of coaching measured by a certified coach on iPad: adequate = 6.

Goal 2. Remove barriers consisting of education policy makers and public preschool programs having insufficient scientific evidence to make data-driven decisions about utilizing a tiered early math program. **Strategy 2.1**. Teachers and tutors implement the tier 1 and tier 2 curricula. **Project Objective 2.1**. All teachers and tutors fully implement Pre-K Mathematics as trained. **Performance Measure 2.1a.** All teachers implement *Pre-K Mathematics* with adequate fidelity (.80) and curriculum dosage (.75) [fidelity score is measured by coach using fidelity form on iPad; incidence of dosage delivery is measured by teacher on iPad]. **Performance Measure 2.1b**. All tutors implement *Pre-K Mathematics Tutorial* with adequate fidelity (.80) and curriculum dosage (.75) [fidelity score is measured by coach using fidelity form on iPad; incidence of dosage delivery is measured by tutor on iPad]. **Strategy 2.2**. Children's math learning is assessed. **Performance Measure 2.2a.** All consented children are screened at the beginning of Pre-K [incidence of assessment is measured by assessor on Experimenter Recording Sheet]. **Performance Measure 2.2b**. All children in the analytic sample are assessed on the CMA at the beginning and end of the Pre-K school year [incidence of assessment is measured by assessor on Experimenter Recording Sheet]. **Performance Measure 2.2c**. All children in the analytic sample are screened at the beginning of K [incidence of assessment is measured by assessor on Experimenter Recording Sheet].

Appropriateness of the Project Design to Improve Math Outcomes of Low-SES Children

This project is designed to use the *Pre-K Mathematics Tiered Instruction* program to support the mathematical learning of low-SES children in public Pre-K programs, specifically to address the SES gap in children's early mathematical knowledge. The tiered structure of this program will enable public Pre-K programs to support both the general population of high-need children they enroll and children who are at risk for mathematical learning difficulties. A math screening instrument, the *Screener for Early Number Sense* will be used to identify children who are at risk.

The curricular intervention used at tier I is *Pre-K Mathematics* ([redacted] & [redacted] 2022). It includes math activities that target the Pre-K classroom and home learning environments of young children. The set of classroom math activities provide conceptually broad support for the development of children's informal mathematical knowledge. The curricular intervention consists of small-group math activities with concrete manipulatives The mathematical content of activities is based on developmental research about the nature and extent of early mathematical knowledge. Units and activities within *Pre-K Mathematics* prepare children for rigorous grade K math standards, including the Common Core State Standards (**Appendix J, p. J16**). Pedagogical content knowledge is embedded into the intervention's math activities to help Pre-K teachers and parents learn to use the classroom and home math activities effectively. 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. Common child errors or misunderstandings and suggested scaffolding to address these challenges are also provided. Teachers also send English and Spanish versions of math activities home to parents weekly and ask them to acknowledge their use of the activities.

The curricular intervention used at tier 2 is *Pre-K Mathematics Tutorial* ([redacted] & [redacted] 2021, It is designed to provide intensive instruction on a core set of math concepts and skills to help children at risk for mathematics difficulties build a strong foundation of informal mathematical knowledge. It is adapted from *Pre-K Mathematics* and uses concrete materials to engage Pre-K children and to support their mathematical learning of concepts related to number, arithmetic, space/geometry, and measurement. The structure of each math activity is designed to be sensitive to the learning needs of Pre-K children who are low performing. The activities are scripted to enable tutors to provide explicit (e.g., modeling) and systematic instruction, and to scaffold children when they encounter difficulty. A downward (less-challenging) extension is provided for children who are not ready for the math activity, and an upward extension is included for children who succeed easily on the activity. *PKMT* is unique in its focus on providing instruction on a core set of concepts and skills that would be expected at the beginning of Pre-K but are not yet developed in this very low- performing population. As such, the first half of the *PKMT* intervention involves foundational math activities (e.g., learning the sequence of number names) and the second half progresses to more advanced Pre-K math activities (e.g., matching concrete sets to number names and numerals). Finally, *PKMT* incorporates a number of the key characteristics that have been found to be effective in interventions for children at-risk for mathematical disabilities: (1) increased intensity of math instruction beyond the Tier 1 curriculum; (2) explicit, systematic instruction that integrates developmental research about mathematics with principles of direct instruction; (3) cumulative review; (4) teaching to mastery; (5) scaffolding for learning and for providing emotional support; and (6) progress monitoring to track children's understanding of each math concept and adjust instruction to their knowledge. For both curricular interventions, digital assessment sheets on an iPad accompany each classroom activity. This enables teachers and tutors to record individual children's exposure to math content (curriculum dosage), their performance during an activity, and to monitor progress toward mastery across the set of math activities (see **Appendix J, pp. J23-J26** for a sample activity).

The *Screener for Early Number Sense* ([redacted], in press) is a criterion-referenced early screening instrument that can be used (1) to identify young students at-risk for mathematical difficulties and (2) to provide information about their mathematical knowledge that can lead to effective early intervention. Development of the *Screener for Early Number Sense (SENS)* was supported by a grant from the Institute of Education Sciences of the U.S. Department of Education. The *SENS* spans the early childhood period from 4 to 7 years of age, when crucial math foundations are built and consolidated. Early screening is a crucial *first* step for catching children who are at risk for falling behind in math and for making sound decisions about who needs further intervention (American Educational Research Association et al., 2014). The *SENS* is comprised of three separate forms for Pre-K, kindergarten, and first grade, respectively. A unique feature of the *SENS* is that the three grade-level forms were vertically scaled using Rasch IRT analysis. Thus, each grade-level form consists of a set of *unique* items that are specific to a grade level and a set of *linking* items that overlap with the adjacent grade level(s). This linked structure allows direct comparison of a child's risk status from one grade (e.g., Pre-K) to the next grade (e.g., K). Each form of the *SENS* has 30 items that assess knowledge of number, number relations, and number operations, and all items are administered to the child in a 15-minute session.

Independent Project Evaluation

Meeting the What Works Clearinghouse Standards

Overview of evaluation plan. The evaluation will use an experimental design (RCT) and rigorous methods to ensure that the evidence of effectiveness obtained from this project meets the WWC standards without reservations. The key personnel on this project have extensive knowledge of and experience with the WWC, including a former WWC math content area leads (Co-PI [redacted]), and current WWC reviewers (methodologist [redacted]; Co-PI [redacted]). Per EIR guidelines, the evaluation will be conducted independently of the program developers (PD [redacted] & [redacted]). The project's methodologist will publicly conduct random assignment to condition and conduct data analysis, and the lead researcher ([redacted]) will lead data collection for the evaluation.

Procedures will be implemented to detect and prevent treatment diffusion (e.g., observations in control classrooms) and other potential threats to internal validity e.g., selection bias (see **Sample and Setting)**. In addition, attrition from the Intent to Treat (ITT) sample of children will be carefully monitored. Multiple tracking procedures will be used to locate and assess as many children as possible on the principal outcome measures at each wave of data collection to minimize both overall and differential attrition.

The overarching goals of the evaluation are to examine the impact of the tiered early mathematics program on math outcomes for (1) high-need Pre-K children who are at-risk for math difficulties at the beginning of Pre-K and (2) high-need Pre-K children who are not at-risk for math difficulties at the beginning of Pre-K. At the child level, the evaluation will measure growth in mathematical knowledge at the end of Pre-K. It will also examine change in the number of children identified as at-risk for math difficulties at the beginning of Pre-K relative to the beginning of K. Confirmatory and exploratory research questions related to the impact of the Pre-K Mathematics intervention are presented below in conjunction with the **Data Analysis Plan** for answering these questions.

Experimental Design. We will evaluate the impact of the tiered early mathematics program using a cluster randomized controlled trial (RCT) in which the Pre-K classroom is the unit of random assignment. Based on a power analysis to detect effects at the end of Pre-K and making assumptions about attrition (see **Statistical Power Analysis**), the RCT will include 84 classrooms (42 treatment and 42 control) and 1,008 children (336 at-risk and 672 not-at-risk). Classrooms will be randomly assigned to the treatment condition (tiered early math program) or the control condition (business-as-usual (BAU)). LEA administrators report that tiered math instruction is not currently utilized. Randomization will be performed within LEAs, and written consent of teachers to participate regardless of condition (treatment or control) will be required prior to randomization. To eliminate the threat to validity posed by "joiners" (children who could join the sample after random assignment), Pre-K classrooms will be randomly assigned to condition only after classroom rosters have been set by the LEA. Any children who are enrolled after this point will not be included in the sample. For all preschool sites (i.e., Head Start centers or elementary schools) with an even number of Pre-K classrooms, half of the classrooms will be randomly assigned to the treatment condition and half to the control condition. When a site has a single Pre-K classroom, we will combine it with a nearby site into one synthetic "site" with an even number of Pre-K classrooms, and then randomly assign half of the Pre-K classrooms to the treatment condition and half to the control condition. This was the procedure used in our i3 Validation study throughout California, and inspection of the pretest balance revealed no imbalance among the children who remained in the design at the end of Pre-K or in K ([redacted], et al., 2018). After random assignment has been conducted, children within classrooms will be identified as at-risk or not-at-risk using screening criteria (see **Sample and Setting**). The resulting design is multi-level, with children (identified as at-risk or not-at-risk) being nested within classrooms, which are located on preschool sites. This multi-level design will be accounted for in the models proposed in the **Data Analysis Plan** (see below).

The two principal threats to internal validity in this study are (1) potential "contamination" (treatment diffusion) between treatment and control conditions, and (2) overall or differential attrition from the Intent to Treat (ITT) sample of children. First, we will protect against treatment diffusion by conducting classroom observations during the intervention year to look for and address any evidence of the *Pre-K Mathematics* or *PKMT* math activities in the Control classrooms. The importance of avoidance of treatment diffusion while the RCT is underway will be explained in meetings with LEA administrators, teachers, and tutors at the beginning of the school year.

PKMT treatment diffusion is less of a threat because tutoring sessions will be conducted outside the classroom. The second threat to internal validity involves attrition, and we will monitor attrition from the ITT sample very carefully over the Pre-K year and though the fall of grade K. Procedures for minimizing this risk are described in the ***Sample retention*** section below.

A three-cohort design will be used to roll out the intervention. Each cohort will have an equal number of preschool classrooms (28) and children (336). The rationale for using a three-cohort design to roll out the intervention is largely pragmatic. It will enable the project to reduce costs and increase implementation quality by utilizing the same small teams of professional development staff and data collection staff in all LEAs over multiple years. It would also enable us to maintain sufficient power by increasing recruitment targets in a later cohort if, unexpectedly, an LEA were to provide fewer classrooms or children than expected in an earlier cohort. Implementation of the tiered early mathematics program will begin with the first cohort of classrooms and children in Years 1-2 of the project, and with the second and third cohorts of classrooms and children in Years 2-3 and 3-4, respectively. We will follow the same recruitment and classroom random assignment procedures in all cohorts.

Counterfactual. In describing the counterfactual in the proposed study, and comparing it to the original study, it is important to consider both the tier-1 and tier-2 math instruction that is provided in BAU classrooms. Based on input from our LEA partners, the tier-1 math instruction in the Pre-K classes comes from two published general curricula, *Creative Curriculum* and *Frog Street*. Neither is listed by the WWC as effective in the content area of mathematics. We have also confirmed from administrators that their teachers do not currently deliver tier-2 math instruction at Pre-K. Also, based on classroom observations in hundreds of Pre-K classrooms over the past decade, we believe the quantity and structure (e.g., group size) of math instruction in these LEAs is similar to the situation found in public preschool programs nationally. A classroom observation will be conducted to describe math instruction in control and treatment classrooms included in the evaluation.

Sample and setting. We have recruited public LEAs (Head Start and state-funded preschool programs) from the Western/southwestern region of the country (see **Appendix C**). The LEAs are already part of the group of programs in this region who have signed MOUs with WestEd to receive professional development in early mathematics from our Western/Southwestern Regional Training Center and to participate in evaluation research. This training center was established through our 2018 EIR Expansion-phase grant. If an LEA were to unexpectedly, our long-time partner, the Region 9 Head Start Association, which includes Arizona, California, Hawaii, Nevada, and the Pacific Region, has agreed to assist in recruitment of a replacement program. All participating LEAs are categorical (i.e., they have family income eligibility requirements for enrollment). Therefore, the entire sample of children from our proposed study will be from low-income families. The largest ethnic groups represented will be Native American (primarily Navajo, Hopi, and Zuni), and Latino (primarily Mexican American) children, with smaller numbers of Black and White children. Native American children will be over-sampled to provide power for a sub-group analysis (see **Power Analysis**)

A sample of 1,008 high-need 4-year-old children from low-income families will be recruited. To be included children must be age-eligible for public kindergarten during the subsequent school year. Based on our prior efficacy study of the tier 2 intervention, classrooms are expected to have 4-6 children who meet screening criterion for at-risk status in math at the beginning of the Pre-K year (see **Performance Data and Outcomes** below). The parental consent rate for child participation in our prior math intervention research has averaged greater than 98% consented. Thus, 4 Pre-K children who meet the at-risk screening criteria and 8 who meet the not-at-risk criteria, and who have parental consent, will be included from each classroom, resulting in a sample of approximately 336 children at tier 2 and 672 at tier 1. If more children are consented than are needed in a classroom, they will be randomly selected, balancing for gender.

Inclusion/Exclusion Criteria. In keeping with all the main definitions of learning disability, intellectual disability will be an exclusion criterion for this trial (American Psychiatric Association, 1994, IDEA, 2004; U.S. Department of Education, 1999; World Health Organization, 2007). Specifically, we will obtain special education classifications from the LEA and will exclude children with an intellectual disability or a severe developmental or behavioral disorder (e.g., Autistic Spectrum Disorder) that would significantly affect group instruction. Children with neurodevelopmental and genetic disorders (e.g., spina bifida), and other developmental disorders (e.g., attention disorder) that meet the screening criteria will *not* be excluded. We adopt this approach based on a need to conduct intervention research that can be generalized to the educational needs of the range of children commonly served by these Pre-K classrooms and research showing a high degree of phenotypic overlap in the cognitive sources of mathematical difficulties in children with and without such disorders (e.g., Barnes et al., 2002; 2006;

Murphy, Mazzocco, & McCloskey, 2009), suggesting similar approaches to intervention are warranted in the absence of evidence to the contrary (Barnes, et al., 2010; Coughlin & Montague, 2010).

Sample retention. To minimize the likelihood of participant attrition, we will work closely with teachers and district administrators to establish a shared understanding of project activities. Teaching staff will be provided stipends for their time in participating in research activities. Regular check-ins with district administration and on-site support visits will keep our participants engaged throughout the entire study. Some child attrition is anticipated during the study due to family circumstances such as relocation. The child attrition rates for our recently completed RCTs have been low, for example 4.6% overall and 1.1% differential from pre-test to posttest in Pre-K ([redacted] et al., 2022). The What Works Clearinghouse guidelines place this rate of attrition within the green rating zone, labeled as low attrition, with a tolerable threat of bias (What Works Clearinghouse, 2020, p. 10). There was no attrition at the classroom level.

We will work to keep overall and differential attrition for this proposed study within the green rating zone. First, we will obtain extensive parent and relative contact information at the time parental consent is given. We will contact parents or guardians twice per year in Pre-K and during the summer between Pre-K and K. Second, we will rely on the LEA database to locate children who transfer between schools/centers and the state tracking system to locate children who transfer between districts. Third, a database of participants will be used to track data collection completion for children for each cohort and year of the study. To increase retention, we will administer tests to children who transfer out of study classes or who are absent on the scheduled test administration days.

Effective Strategies and Guidelines for Replication

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 plans teachers and tutors follow, (2) the level of fidelity at which teachers and tutors implement the tier 1 and tier 2 math interventions, (3) the curriculum dosage levels delivered to children by teachers, tutors, and parents, and (4) use of screening (SENS) and progress monitoring (Math Mastery instrument) data by teachers and tutors. 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 teacher or tutor has begun to fall behind in the curriculum plan; trainers will have been trained to assist teachers and tutors by providing feedback, discussing why the curriculum is being implemented slowly, and working with the teacher to solve this implementation challenge.

Also, findings from the planned sub-group analysis of math outcomes in Native American children will provide guidance for sample sizes needed for studies examining math outcomes in other populations. The effect sizes obtained will guide power analyses for such studies.

Key Project Components, Mediators, Outcomes, and Implementation Metrics

The following sections provide information on the key components included in the *Pre-K Mathematics Tiered Instruction* program, as well as a summary of the measures and data collection activities for the project. These components and measures are represented in Figures 1a-1c of the logic model in **Appendix G**. A detailed timeline of the research measures and data collection activities is provided in **Appendix J**.

Key components of the *Pre-K Mathematics Tiered Instruction* program. The promising new educational strategy that will be implemented and evaluated in the proposed project is a tiered early math program. The key components of this program are represented in Figure 1a of the logic model (see **Appendix G)**. It includes early math screening of high-need children, using the Pre-K version of the Screener for Early Number Sense (SENS), to identify children who are at-risk or not-at-risk for mathematical difficulties. This identification at the beginning of the Pre-K school year determines which children will receive only tier 1 (*Pre-K Mathematics*) math instruction and which children will receive both tier 1 (*Pre-K Mathematics)* and tier 2 (*Pre-K Mathematics Tutorial*). The tiered early math program also includes screening of children as they enter kindergarten, using the K version of the SENS to identify children who are at-risk or not-at-risk for mathematical difficulties. Screening data from the Pre-K and K time points will be analyzed to determine whether fewer treatment children are identified as at-risk in K than in Pre-K. Detailed descriptions of *Pre-K Mathematics* and *Pre-K Mathematics Tutorial* are provided in the **Project Design**.

Mediation. The Early Mathematics Classroom Observation (EMCO) instrument (see **Appendix J**) will be used to provide quantitative and qualitative data on tier 1 and tier 2 classroom mathematics instruction and small group tutoring sessions in participating children's classrooms. The EMCO will be used to measure the amount of classroom time teachers devote to mathematics. On this dimension, interrater reliability of the EMCO is very high, .98. Intentional, small-group minutes of math instruction is the mediation variable of interest for this study (see Figures 1b and 1c of the logic model, **Appendix G**).

Child-level moderation. We will assess children's attention and working memory to determine whether child math outcomes are moderated by these cognitive systems (see **Appendix G**). Attention will be measured by direct child assessment using the *Child Attention Networks Test (Child ANT)* to measure alerting, orienting and executive aspects of attention (Rueda et al., 2004). It is the measure used in the attention training literature that shows effects in preschool children (Rueda, 2005). Test-retest intraclass correlation coefficients is .92 with a 95% confidence interval; convergent validity for 3- to 6-year-olds, measured using WPPSI-III Block Design, is positively correlated with Child ANT, $r(81) = .60$, $p < .0001$.

Attention will also be measured by use of a teacher rating measure The Child Behavior Questionnaire (CBQ; Rothbart et al., 2001), as adapted for use with teachers (Eisenberg et al., 2004), consists of three subscales: attention focusing, inhibitory control, and impulsivity. For each subscale, the classroom teacher rates a series of statements about the child's behavior. The CBQ has been found to be a highly reliable measure of children's effortful control behavior. Cronbach's alpha (also referred to as coefficient alpha), which measures the internal consistency or reliability of a set of items within a test, has been calculated for the CBQ by Eisenberg et al. (2004) and found to be very robust (above 0.85- 0.88).

Working memory will be assessed using the Follow Froggy assessment, a preschool-friendly measure of visual-spatial working memory. Children must replicate the series of jumps between lily pads that a frog makes starting with a span of 1 and going to a span of 7. Children's total accuracy score is used in analyses. Internal consistency for this task in 4- and 5-year-old children is .70 and relations of concurrent performance with measures of phonological awareness and vocabulary range from .22-.26, and from .26-.31 with measures of non-symbolic arithmetic and number naming; test-retest reliability was .70 (LeFevre et al., 2010).

Mathematics outcomes and screening measures. The Child Math Assessment is a measure of preschool children's informal mathematical knowledge across a broad range of concepts and skills, including number, arithmetic operations, space and geometry, measurement, and patterns ([redacted], 2018) (see Appendix J for a description of CMA tasks). The CMA is sensitive to the development of some math concepts supported by the tier 1 and tier 2 math interventions, but it is not over-aligned (i.e., it does not use the same tasks or materials). The CMA is comprised of 9 tasks, with multiple items per task, and the range of task difficulty is appropriate for children from three to five years of age. All tasks on the CMA are administered individually to children in one 20-minute session, and the instrument is available in both English and Spanish. The psychometric properties of the CMA are very good for preschool-aged children. Test-retest reliability over a 2-week interval is .91, and internal consistency (stratified Coefficient Alpha) is .92. Furthermore, with respect to concurrent validity, CMA scores were found to be positively related to TEMA-3 scores ($r = .74$, $p<.01$) for 4- and 5-year-old children.

The Screener for Early Number Sense (SENS- Pre-Kindergarten Form and SENS- Kindergarten Form) will be administered in Pre-K and K, respectively, to all children in the study. This will provide screening data to determine whether fewer treatment children are identified as at-risk in K than in Pre-K. Reliability and validity analyses indicate that the *SENS* has robust psychometric properties. Receiver operating characteristic (ROC) curve analyses were used to determine the recommended d-based cut scores for identifying risk status on each form of the SENS. The *d*-based cut point identifies the score on the screener that produces the least difference between sensitivity and specificity. Furthermore, ROC analyses revealed that the *SENS* reached strong levels of diagnostic accuracy as measured by Area Under the Curve (AUC). Predictive validity of the *SENS* was assessed using the Test of Early Mathematics Ability, Third Edition (TEMA-3; Ginsburg & Baroody, 2003) as the criterion measure of general math achievement. All correlation coefficients between the SENS at each grade and the TEMA-3 the following year were high (>0.79). Finally, both internal consistency reliability (KR-20) and test-retest reliability were computed for all forms of the SENS and found to be very high (>0.9).

Data collection procedures. Child outcomes and moderation data, and classroom mediation data will be collected by data collectors trained and certified by the Independent Evaluator, as specified in the Measures and Data Collection Timeline (**Appendix J, p. J3**). Children will be assessed individually in a quiet location at their school. Classroom observations of teachers' math practices will be conducted in all treatment and control classrooms. Assessors and classroom observers will be blind to the condition assigned to classrooms and children.

Managing data collection. [redacted], PI at U. Nevada, Reno, will be responsible for carrying out the data collection plan to ensure high-quality data collections that are completed on time and on budget.

Implementation metrics and thresholds. Essential dimensions of implementation of the tier 1 and tier 2 interventions will be measured using the instruments listed below and provided in **Appendix J, pp. J15-J19, J25-J26**. These dimensions are listed in Figures 1b and 1c of the logic model (**Appendix G**). Also, thresholds for adequate and for high quality implementation are given; these thresholds were set in prior projects and will be used in the proposed project.

For *Pre-K Mathematics*, essential aspects of implementation will be measured: (1) Teacher workshops: 6 days (45 hours) are provided; adequate attendance = 6 days; attendance data will be collected on teacher sign-in sheets by WestEd regional trainers; adequate = 6 days of attendance, (2) fidelity visits made per classroom by curriculum coaches; adequate = 8-10 visits, (3) Classroom curriculum dosage; adequate, =75%+, (4) Home curriculum dosage: adequate =75%+, (5) Intervention fidelity: adequate = .80+.

For *Pre-K Mathematics Tutorial*, 4 essential aspects of implementation will be measured: (1) Tutor Workshops: 4 days (28 hours) plus certification are provided; adequate attendance = 6 days; attendance data will be collected on teacher sign-in sheets by WestEd regional trainers, (2) Coaching visits per tutor; 6 visits; 6 visits=adequate, (3) *PKMT* curriculum dosage; adequate, = 75%+, (4) Intervention fidelity: adequate =.80+.

Workshop attendance will be collected using teacher/tutor sign-in sheets. Other data will be collected on iPads by curriculum coaches, teachers, and tutors, using cloud-based software and data storage. Incidence of fidelity support visits and teacher/tutor intervention fidelity will be collected electronically on a tablet used by curriculum coaches (*Pre-K Mathematics* Fidelity of Intervention Form; *PKMT* Fidelity of Intervention Form). Incidence of delivery of classroom/tutorial curriculum dosage, children's performance (Assessment Record Sheet), and monitoring of children's progress in learning math (Math Mastery Sheet) will be collected electronically on an iPad used by teachers or tutors. Home curriculum dosage will be reported electronically by some parents and by paper forms (Parent Feedback Form) by others. The iPads used by curriculum coaches, teachers, and tutors use cloud-based software that collects the data and provides our project staff with access to it for (almost) real-time monitoring. We are already collecting these types of data in this manner in other projects. Fidelity ratings will be made by certified curriculum coaches and regional trainers. Inter-rater reliability will be calculated from ratings made by a regional trainer and certified curriculum coach during two co-fidelity visits per curriculum coach. In prior studies, these reliabilities have exceeded 80% agreement. See **Appendix J** for sample data collection forms.

Periodic Assessment of Progress

AS described above (see **Project Design**), the project outcomes have been specified and will be measured. Periodic assessment of progress toward achieving these outcomes will be reportable cohort-by-cohort. At a more molecular level, implementation data that will be collected on coaches', teachers', and tutors' iPads will permit periodic assessment of progress toward achieving intended child math achievement and implementation outcomes, document the degree to which the study met the targets associated with these outcomes, and document the performance feedback provided to teachers and tutors. To assess progress toward the study's goal of achieving intended child math outcomes, we will use the Math Mastery instrument, which provides data on treatment children's math learning continuously during implementation (**Appendix J**). The target is for each child to master each small group math activity. Teachers and tutors collect Math Mastery data on the activity they are teaching during each small group session. They can see children's progress (or lack of progress) in learning a small group math activity when additional doses of the activity are given in small group sessions later in a review days r. Progress is measured by the degree to which children learn to independently solve the math problems or tasks included in the activity. A rating of "mastery" by the teacher or tutor indicates that a child has independently solved the problems or tasks comprising the activity without needing scaffolding by the teacher or tutor. Thus, the monitoring of progress in children's math achievement outcomes is done by teachers and tutors on an activity-by-activity basis across the school year. To provide formative feedback to teachers and tutors, curriculum coaches will review Math Mastery data periodically during classroom or tutoring session visits. Curriculum coaches will help teachers and tutors learn to use Math Mastery data to determine which children need additional review. In addition, the use of the SENS at the beginning of K will provide K teachers and elementary school administrators needed information about progress made in preparing children to learn kindergarten mathematics.

Also, teachers' and tutors' progress toward becoming able to implement the tier 1 or tier 2 math intervention with fidelity will be measured through (1) periodic classroom or tutoring session fidelity visits by curriculum coaches and (2) curriculum dosage data teachers and tutors collect on their tablets. The visits by curriculum coaches will be formative evaluations of implementation fidelity and dosage delivery (see Fidelity of

Intervention forms in **Appendix J**) with feedback provided (e.g., tips on effective scaffolding of children who are struggling) to help teachers develop professionally. Thus, procedures will be in place to provide performance-related feedback to teachers, tutors, and administrators on progress in preparing at-risk and not-at-risk children for demanding, standards-based mathematics instruction

Research Questions

A goal of this project is to evaluate the efficacy of a tiered early math program, which includes (1) a tier 1 math intervention, *Pre-K Mathematics*, (2) an intensive tier 2 math intervention, *Pre-K Mathematics Tutorial (PKMT)*, and (3) a screener, SENS, to identify children at-risk for mathematical difficulties. A sub-study is included to determine whether tiered math instruction is effective for Native American children. Secondary objectives concern the identification of possible moderators (e.g., child attention; working memory) and mediators of hypothesized effects of *PKMT* on math outcomes. We propose to conduct a randomized controlled trial to test the principal hypotheses and explore additional research questions for this study. Children will be assessed on the CMA at fall of Pre-K (pretest) and spring of Pre-K (posttest). Children will also be given a math screening test (SENS) in fall of Pre-K and fall of K.

Confirmatory

Aim 1a. Tiered instruction vs. BAU Control for high-need children in general (12 children per classroom).

To test whether tiered instruction (*Pre-K Mathematics* and *PKMT*) has an impact on math outcomes for high-need Pre-K children: Hypothesis 1. CMA scores will be better at Pre-K post-test for children receiving tier 1 or tier 2 instruction in the T condition than for children in the BAU condition.

Aim 1b. Tiered instruction vs. BAU Control for high-need Native American children (12 children per classroom).

To test whether tiered instruction (*Pre-K Mathematics* and *PKMT*) has an impact on math outcomes for high-need, Native American Pre-K children: Hypothesis 2. CMA scores will be better at Pre-K post-test for children receiving tier 1 or tier 2 instruction in the T condition than for children in the BAU condition.

Aim 2. Tier 2 vs. BAU control (4 children per classroom).

To test whether tier 2 instruction (*PKMT)* has an impact on math outcomes for high-need Pre-K children who are at risk for math difficulties at beginning of Pre-K: Hypothesis 3. CMA scores will be better at Pre-K post-test for children receiving tier 2 instruction in the T condition than for children in the BAU condition.

Aim 3. Tier 1 vs. BAU control (8 children per classroom)

To test whether tier 1 instruction (*Pre-K Mathematics)* has an impact on math outcomes for high-need Pre-K children at beginning of Pre-K: Hypothesis 4. CMA scores will be better at Pre-K post-test for children receiving tier 1 instruction in the T condition than for children in the BaU condition.

Exploratory

To test whether tiered instruction has a lasting impact on math knowledge of children at the beginning of kindergarten, the SENS will identify fewer T children, relative to C children, as being at-risk for mathematical difficulties at the beginning of K.

Research Question 5. Will fewer T children, relative to C children, be identified as being at-risk for mathematical difficulties at the beginning of K?

Research Questions 6a-6c. Will attention scores moderate the effect of (a) tiered instruction, (b) tier 2 instruction, or (c) tier 1 instruction?

Research Questions 7a-7c. Will visual-spatial working memory scores moderate the effect of (a) tiered instruction, (b) tier 2 instruction, or (c) tier 1 instruction?

Research Question 8. Will minutes of math instruction mediate the impact of (a) tiered math instruction, (b) tier 2 math instruction, or (tier 3) math instruction as compared to BaU at post-test?

Research Question 9. Will math outcomes of treatment children who were in Pre-K during the pandemic differ from math outcomes of treatment children in an RCT that was conducted prior to the pandemic ([redacted] et al., 2022)?

Statistical Power Analysis

The proposed impact evaluation study has ample statistical power to detect the effects of the tiered early math program on (1) children at-risk for mathematical difficulty, (2) children not-at-risk for mathematical difficulty, and (3) all (at-risk and not-at-risk) high-need children. These are the contrasts we propose to examine under the confirmatory research questions. A total of 84 classrooms (42 treatment and 42 control) will be included in the RCT, with 8 children at tier 1 and 4 children at tier 2 per classroom. With these sample sizes, the evaluation will be able detect impacts on children's math achievement, measured by the CMA, of 0.25 SD (see Appendix J for the method and assumptions used in these power calculations). Prior studies of *Pre-K Mathematics* found effects on the CMA of approximately 0.5–0.9 SD ([redacted] et al., 2018). The one efficacy study of Pre-K Mathematics tutorial found effects on the CMA of 0.60 ([redacted] [redacted] & [redacted], 2019).

Native American children will be over sampled to provide power for a subgroup analysis. Inclusion of 46 classrooms (23 T and 23 C) with 12 children (4 at-risk and 8 not-at-risk) per classroom will make it possible to detect effects of 0.34. This MDES is well below the effect size (0.60) for the CMA obtained in our prior study of PKMT's efficacy study (see **Evidence Form**)

The proposed study also has adequate statistical power to detect moderation effects at the child level (research question 7). Conservatively, we expect these treatment X moderator interaction effects to be approximately 0.25–0.45 SD, which is half the size of the main effect, 0.5–0.9 SD, found in prior RCTs.

Data Analysis Plan

Effects on math achievement of high-need children and those at-risk for math difficulties (Aims 1a, 1b, 2, and 3). We will use a two-level hierarchical linear model in which children are nested within clusters defined by the Pre-K classrooms that constitute the unit of random assignment. Children's scores on the CMA spring Pre-K assessment will be the dependent variable. We will include an indicator for treatment or control group status, age and, following guidance in the WWC Review Protocol for Preparing Young Children for School (WWC, 2020), CMA fall Pre-K pretest score as covariates in the model. If needed, we will also include randomization block dummy variables to account for any differences in probability of assignment to the treatment condition across blocks resulting from cases where we could not form blocks with even numbers of classrooms. Our primary analysis will use an ITT framework which will include all children whom we are able to assess at baseline and follow-up in their original, randomly assigned study condition. A secondary analysis will focus on a treatment-on-the-treated sample comprising children who received at least 75% of their classroom math dosage as recorded on teachers' Assessment Record Sheets in treatment classrooms and as measured by attendance records in control classrooms.

Effect on being identified as at risk for math difficulties at the beginning of K (research question 5). We will use a two-level hierarchical linear model as described above, except the outcome variable of interest will be whether children are identified as at-risk for math difficulties at the beginning of K.

Attention scores and working memory scores as moderators of the effects of tiered instruction, tier 1 instruction, and tier 2 instruction on children's math achievement (research questions 6a–6c and 7a-7c). These moderation analyses will be similar to the analyses discussed under Aims 1a, 1b, 2, and 3, except we will include two additional terms: attention score measured at baseline and an interaction term for treatment group status * attention score. Including these terms allows us to assess whether children with different baseline attention scores experience differential treatment effects.

Minutes of math instruction as a mediator of the effects of tiered instruction, tier 1 instruction, and tier 2 instruction on children's math achievement (research question 8). To gain insight into the mechanisms by which the tiered early math program affects child math achievement, we will conduct mediation analysis using structural equation modeling (Gunzler et al., 2013; Imai, Tingley, & Keele, 2010). A key component of this analysis is the path diagram that depicts the hypothesized relationships among the intervention, minutes of math instruction, and math achievement (See Path Diagram in **Appendix J**, which is simplified). The goal of this analysis is to understand the extent to which changes in minutes of math instruction account for the effect of tiered instruction, tier 1 instruction, and tier 2 instruction on children's math achievement.

Learning loss (research question 9). Math outcomes of children from two studies will be compared. In both studies the same outcome measure was used. Data for one were collected on children prior to the pandemic; data for the proposed project will be collected on successive cohorts of children who experienced the pandemic at different ages. The analysis goals are to determine whether math growth from pretest to posttest was greater overall or for some cohorts in the present study conducted during the pandemic than in the study conducted prior to it.

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