Appendix B.3:
School Readiness and Early Childhood Education: What Can We Learn from Federal Investments in Research on Mathematics Programs?

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Programs designed to promote young children's school readiness have focused primarily on language and social emotional development. While these remain important skills for young children to acquire, there is a growing awareness that readiness for mathematics is also critical. Promoting school readiness for mathematics is particularly important for low-income and/or ethnic minority children who are at greater risk for beginning kindergarten with markedly lower math skills (Lee & Burkham, 2002). In fact, recent research shows that children's mathematics ability at kindergarten-entry is a better predictor of future academic success than their reading achievement (Duncan et. al., 2007). Preschool and prekindergarten programs can buffer children against school failure (Bogard & Takanishi, 2005) and prepare young children for success in primary school mathematics (Arnold & Doctoroff, 2003; Bogard & Takanishi, 2005; Goldbeck, 2001). Considerations like these have led many states to develop early learning standards for mathematics.

In spite of the evidence that early childhood education is the most promising and cost-effective way to positively affect the development of children at-risk for later school failure (Reynolds, 2005), there has been widespread reluctance to teach mathematical concepts to young children. This is because many mathematics educators were not convinced that young children could learn these concepts and because it was unclear how best to teach them (Perry & Dockett, 2002). In fact, some early childhood educators continue to resist the use of any planned teaching or curricula given their long held beliefs that young children need to learn on their own in a child-centered holistic environment and that deliberate teaching is not "developmentally appropriate" (Golbeck, 2001). In addition, many teachers' own fear of math is an obstacle to their willingness to teach mathematics (Ginsburg, Lee, & Boyd, 2008). The result has been that mathematics education has traditionally not figured prominently in early childhood education programs. For example, two major early childhood programs that account for a large portion of the market, Creative Curriculum and High/Scope, have traditionally not emphasized a comprehensive mathematics curriculum. However, both of these programs are in the process of expanding their mathematics offerings.

The historical reluctance to teach mathematics to young children stands in stark contrast to research showing that young children can understand mathematics in complex ways. While it was once thought that young children were incapable of abstract or logical thought because they were in Piaget's preoperational stage, recent research shows that young children can understand basic aspects of number and operations, geometric shapes, spatial relations, measurement, and patterns (Ginsburg, Lee, & Boyd, 2008; Perry & Dockett, 2002). Children's "everyday" mathematical skills can be cultivated and extended at this age level in ways that support a more advanced understanding of mathematical concepts (Ginsburg, Lee, & Boyd, 2008).

In response to the recent research findings demonstrating that young children are eager learners of everyday mathematics, leading mathematics and early childhood education professional organizations now stress the importance of deliberate early childhood mathematics education (National Association for the Education of Young Children and National Council of Teachers of Mathematics, 2002). Their position is that curricula providing organized activities designed to promote students' understanding of mathematical concepts can be used in a deliberate manner by teachers, while still allowing children the opportunity to play and explore the world flexibly (Ginsburg, Lee, & Boyd, 2008; Perry & Dockett, 2002). This approach to early mathematics education fits into prevailing views of quality early childhood education: children should play and be taught, and both should occur in a warm, and nurturing environment.

The goal of this paper is to examine the effectiveness of new research based mathematics curricula that attempt to respond to the call for organized programs of mathematics learning for young children. Given that relatively little rigorous research on preschool mathematics programs has been conducted—whether federally-funded or not—this paper will review research that has been supported by a number of different funding streams: federally-funded studies that were part of the PCER and ISRC initiatives; federally-funded Head Start research; studies funded through other federal programs, including the Institute for Education Science (IES) and the National Science Foundation (NSF); as well as foundation-funded research based in the U.S. and international research. All of the studies reviewed include pre-kindergarten or preschool-aged children (e.g., children who are approximately four years old) in their samples. These children may be attending organized programs like Head Start, or may be in other "preschool" or child-care center settings. In addition, all of the studies focused on improving the math skills of children from low-income families as these children are most at risk for beginning formal schooling with a poorer understanding of mathematics than their non-poor peers.

The first section of the paper focuses on mathematics-specific curricula whose development and/or evaluations have been supported by the federal government, as well as two curricula that were developed or evaluated by other funding sources. The second section will review federally-funded research on comprehensive curricula that include a mathematics component. In each of these sections, we will identify the funding stream and, when applicable, the research initiative supporting the research. The paper concludes with a discussion of what the research does and does not tell us at this point, and recommends directions for future research that would better illuminate the processes of teaching and learning that support mathematics learning in early childhood settings, as well as research designed to determine which underlying components of curricula and implementation are beneficial under the varying preschool and childcare settings that serve children most at risk for starting school with academic skills that lag behind those of their peers.

What Can We Learn from Federally-Funded Research on Early Childhood Mathematics Curricula?

Although leading professional organizations call for research-based curricula, the meaning of "research based" is a bit problematic. A restrictive definition might be that the curriculum should derive directly studies that focus on how mathematics should be taught. By this criterion, almost no programs would qualify. The designs of early childhood mathematics curricula are based on research investigating the development of children's mathematical thinking in the absence of instruction, not from teaching experiments. Thus, a more accurate definition of "research-based" curricula is one that is inspired by research on young children and attempts to translate the research into an organized program of teaching. The danger with this definition is that it can be over-inclusive. Publishers in particular may claim that their programs meet whatever standards are in place at the moment and, not surprisingly, will advertise that virtually any curriculum for young children is research-based (or developmentally appropriate or whatever the slogan of the day may be). Their goal is sales, not scientific rigor.

Our approach is not to take too seriously the claim of a basis in research. After all, the major question is not whether the program derived from research but whether it is effective. Sometimes, practical applications precede and indeed inspire scientific investigation (Stokes, 1997). A creative curriculum developer may have a hunch, possibly based on some informal exploration, that an activity might work, and indeed it might. The issue is not whether the program is research-based but whether it has been evaluated and is shown to be effective in improving learning outcomes. While to date there have been few rigorous studies examining the effectiveness of mathematics curricula for young children (National Research Council, 2004; D. Clements & Sarama, 2008), the studies that have been conducted indicate that young children from low-income families can indeed benefit from curricula designed specifically to address mathematics learning.

Federally-Funded Cluster Randomized Studies of Mathematics-Specific Curricula: PCER, IES, and NSF Research

Federal dollars have supported the rigorous evaluation of three mathematics-specific early childhood curricula, although the evaluation of each has been supported by a different funding stream. An intervention consisting of the *Pre-K Mathematics Curriculum (PreK Math;* Klein, Starkey, & Ramirez, 2002) supplemented with the *DLM Early Childhood Express Math software (DLM;* D. Clements & Sarama, 2003) was evaluated as part of the Institute for Education Sciences' (IES) Preschool Curriculum Evaluation Research program (PCER; PCER Consortium, 2008). Development and evaluation of the *Building Blocks* curriculum (Sarama, 2004; D. Clements & Sarama, 2003, 2008) has been supported by the National Science Foundation. *Building Blocks* is a designed for use with children as young as three-years-old. The evaluation of the *Big Math for Little Kids* curriculum (BMLK; Greenes, Ginsburg, & Balfanz, 2004) was supported by a research grant from IES (M. Clements, Lewis, and Ginsburg, 2008). *BMLK* was developed for use by pre-kindergarten and kindergarten students.[1]

The three curricula share a number of characteristics, including the types of professional development offered to teachers, the contexts in which the curriculum is designed to be taught, and the scope of the curricula. It is important to note that the similarities noted here do not represent "precise" similarities across the curricula, but rather broad characteristics that they share. The specific representation of each of these characteristics certainly varies across the three curricula, possible in meaningful ways that result in differences in their effectiveness.

Professional development activities were a component of the treatment condition in the rigorous cluster randomized studies used to evaluate each of the curricula. All three of the evaluations included at least one "intensive" workshop on the curriculum before the beginning of the school year. Each of the interventions was also supported throughout the course of the study with regularly scheduled, periodic professional development sessions for teachers. These ranged from bi-weekly, one-on-one sessions in a teacher's classroom to bi-monthly "refresher" courses in which groups of teachers met to review particular aspects of the curriculum.

Another shared characteristic of the curricula is that all are designed to utilize multiple contexts for teaching mathematics. In terms of at school activities, the three curricula include whole class learning activities and small group activities. The curricula also incorporate information and activities designed to be sent home for parents and children to work on together at home.

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[1] It should be noted that the authors of this paper conducted the evaluation of BMLK (Clements, Lewis, and Ginsburg, 2008) and that Ginsburg is one of the curriculum's developers.

A third characteristic shared by the these three curricula is that each was designed to be a comprehensive mathematics curriculum covering multiple important mathematics domains , such as numbers, counting, and operations; shapes (geometry); measurement; and pattern. It's important to note that here we are referring to very broad mathematical domains and that the specific content and emphasis of each curriculum may well vary. The major point is that each curriculum sets out to cover multiple important mathematical domains rather than just number and operations or just shapes. See Table 1 for a comparison of the domains covered (broadly defined) by curricula.

The *PreK Math/DLM, Building Blocks,* and *BMLK* curricula also differ in several possibly important ways. While it is true that the three curricula cover many of the same (broadly defined) mathematics domains, it is certain that the specific topics covered within each domain, the scope of coverage for each topic (in terms of depth and/or breadth), the types of activities and lessons developed to teach each topic, and the ways in which various topics and/or domains are integrated with each other varies across the curricula. Investigating the extent of this variation is beyond the scope of this paper. However, a review of published reports and descriptions of the curricula provide some information about these differences. For example, both *PreK Math/DLM* and *Building Blocks* incorporate regular use of computer software, while *BMLK* does not include a software component.

The findings of the rigorous evaluations of the developmentally appropriate mathematics-specific curricula stand in stark contrast to the findings from the Head Start Impact Study. The Head Start Impact study compared children randomly assigned to attend Head Start to a control group of children who, for the most part, attended some other type of center-based care on a number of cognitive domains. Among four-year-olds, the study found a statistically significant positive impact of Head Start attendance on four of eight language-related cognitive domains, but no difference in early math skills (U.S. Department of Health and Human Services, 2005). Given that two of the mathematics curricula reviewed above were evaluated in Head Start classrooms, it appears that the Head Start Impact Study's lack of significant findings regarding math is due to the dearth of effective early childhood mathematics curricula, not Head Start. In fact, the study's final report points to the need for effective early childhood mathematics curricula and teacher professional development in math education (US DHHS, 2005).

While all three of these curricula have been rigorously evaluated using cluster randomized trials, including variation in the length of the studies and the age of children in the study samples, mathematics outcome measures used in the evaluations, and the types of classrooms settings in which the mathematics curricula were evaluated. As we'll discuss below, these differences make it difficult to compare the relative effectiveness of the curricula, other than to conclude that all three demonstrate effectiveness in improving children's understanding of mathematics. The *PreK Math/DLM* and *Building Blocks* evaluation studies examined the impact of each curriculum over the course of children's pre-kindergarten year, and the research took place in a combination of Head Start classrooms and state-funded prekindergarten classrooms. The *BMLK* evaluation, on the other hand, examined the curriculum's impact over the course of children's pre-kindergarten and kindergarten years among children attending child care centers that are subsidized by the New York City Administration for Child Services and, thus, didn't include either Head Start classrooms or state-funded pre-kindergarten programs.

Another important difference across the studies is that each evaluation utilized a different mathematics assessment as the outcome variable. Both *PreK Math/DLM* and *Building Blocks* used assessments developed by the curriculum's developer (and evaluators), neither of which is nationally normed. Both sets of authors clearly articulate that their assessment is not overly aligned with the curriculum; they are designed to evaluate children's understanding of the concepts taught, but do not use the same activities and materials that are part of the curriculum. At the suggestion of *IES, BMLK* used the mathematics assessment developed for the Early Childhood Longitudinal Study, Birth Cohort (ECLS-B; National Center for Education Statistics) which is nationally normed. Each of the assessment procedures (using versus not using an assessment designed to evaluate a particular curriculum) has its strengths and weaknesses. On the one hand, using an assessment designed to evaluate a particular curriculum is likely to be able to provide a more nuanced understanding about what concepts the curriculum was more (or less) successful at teaching. On the other hand, an assessment that has not been nationally normed will not provide information about how children compare to their peers throughout the country both before and after being taught with the curriculum.

Results from the studies indicate that all three curricula were effective in promoting children's mathematics learning. The effect sizes for the studies were .43 for *BMLK* (compared to control classrooms; M. Clements et al., 2008), .55 for *PreK Math/DLM* (compared to control classrooms; Klein, Starkey, D. Clements, Sarama, & Iyer, in press), and for *Building Blocks* the effect sizes were 1.07 (for the comparison with control classrooms) and .47 (for the comparison with classroom using *PreK Math/DLM*[2] ; Clements & Sarama, 2008). See Table 2 for additional details on the evaluation studies. In all three studies, the control classrooms used a variety of curricula, including Creative Curriculum, High/Scope, Montessori, or other local curricula.

We should note that the difference between the *BMLK* and control students did not become statistically significant until the second year of the study (the year following pre-kindergarten[3]), while the *Building Blocks* and *PreK Math/DLM* studies found statistically significant differences at the end of the pre-kindergarten year. This could be due to several factors. One possibility is that our use of the ECLS-B math assessment (a standardized test that was designed as a general assessment of mathematics learning, and not developed to test a particular mathematics curriculum) resulted in a stricter test of the curriculum's effectiveness and, as a result, additional months of exposure to the curriculum were necessary before differences in children's learning could be detected by this assessment. A second possibility is that more than seven months of exposure to the curriculum were necessary before group differences emerged. In our opinion, the fact that the overall math achievement of children in the study was near the national median score throughout the course of the

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2 There are several reasons we do not draw any conclusions about the relative efficacy of Building Blocks and *PreK Math* even though results from the *Building Blocks* evaluation study found that children using it scored significantly higher than children using *PreK Math.* First, the evidence from the federally funded evaluations of the two curricula indicates that both *PreK Math* and *Building Blocks* are more effective than the control curricula used in the control conditions. Second, both evaluations were conducted using mathematics assessments designed by the curriculum developers/evaluators. As we said before, this is not to suggest that that either assessment tool is overly aligned with a specific curriculum or to question either assessment's validity. Rather, we suggest that it is premature to draw conclusions regarding the relative effectiveness of the two curriculum based on two studies, each of which used a different mathematics assessment. In fact, both curricula have been evaluated by the What Works Clearinghouse and received its highest rating: "strong evidence of a positive effect with no overriding contrary evidence".

3 ACS child care centers offer a kindergarten year for their students, and many students choose to complete the kindergarten year at the child care center rather than transitioning into a public elementary school. Many kindergarten programs in New York City are half-day, while the ACS child care centers offer full-day care and are intended to meet the needs of working parents.

study rules out a third possibility: that the curriculum is too advanced for preschoolers and not appropriate until children reach kindergarten.

An advantage of using the ECLS-B math assessment in the *BMLK* evaluation is that we were able to determine the extent to which *BMLK* helped reduce the achievement gap between children from low-income families and the national average. Specifically, in the fall of pre-kindergarten the average student score on the ECLS-B was at the 48^{th} percentile, but increased to the 56th percentile by the end of the prekindergarten year, and was at the 55^{th} percentile at the end of the kindergarten year.

In summary, evaluations of all three curricula demonstrated that they are effective, with effect sizes ranging from moderate to large. Furthermore, the fact that their effectiveness was demonstrated across a variety of classroom contexts (Head Start, state-funded prekindergarten, and NYC ACS subsidized child care centers) suggests that these comprehensive mathematics curricula are likely to be effective in promoting mathematics-related school readiness among children from low-income families.

A Federally-Funded Cluster Randomized Study of a Comprehensive Curriculum: ISRC research

Among the studies that were funded as part of the Interagency School Readiness Consortium, only the *Children's School Success* curriculum (CSS) included a component designed specifically to advance children's mathematics knowledge. Odom and his colleagues (Leiber et al., 2007; Odom et al., 2007a and 2007b) refer to CSS as an early childhood education model designed to combine science, language, literacy, math, and social skills into a "meaningful learning experience". The mathematics component of the curriculum is described as being adapted from D. Clements and Sarama's *Building Blocks* curriculum, but details regarding the extent to which the curriculum was modified are not provided.

Based on research reports (consisting of slides and posters from conference presentations), it is difficult to discern whether or not CSS was effective in promoting more advanced mathematics knowledge among the children attending Head Start centers where it was implemented. Analyses for this study are still underway, and, to date, none of the presentations provide statistical results demonstrating the curriculum's effectiveness. However, there are multiple presentations that examine the impact of treatment fidelity and children's attendance rates on children's math achievement scores. As would be expected, fidelity of implementation is associated with higher student math scores at the end of the school year.

Other Early Childhood Mathematics Research

In light of the fact that only three early childhood mathematics curricula have been subjected to federally-funded rigorous evaluations, this research review will briefly review additional curricula. They include curricula that were evaluated by non-federal funds and/or by study designs that were not as methodologically rigorous or extensive as those for *Building Blocks, PreK Math/DLM,* and *BMLK*.

The National Science foundation has funded recent research on the '*Round the Rug* curriculum (Casey, 2004), which is a supplementary language arts-based curriculum designed to promote children's understanding of key mathematical concepts including pattern, geometry (shape), measurement, and graphs. The curriculum consists of six books that teachers use to lead lessons that integrate oral story-telling with hands-on mathematics. The impact of one of the lessons (on geometry) has been evaluated in a smaller-scale random assignment study involving six kindergarten teachers (Casey, Erkut, Ceder & Young, 2008). This study found that a lesson taught using both the story-telling and hands-on components promoted greater mastery of the material than the hands-on lesson alone.

The Head Start-University Partnership, a program of the US DHHS Administration for Children and Families, has supported research on a preschool mathematics curriculum that Katherine Sophian developed for use with three- and four-year olds. The curriculum consists of weekly activities that parents and teachers are to complete with children. The emphasis of the program is on measurement with various units and exploring the relationships between shapes rather than identifying features of shapes (i.e., the number of sides or angles). The curriculum has been evaluated in a study of three Head Start centers with children ranging in age from 2.5 years old to 4.6 years. This study found that use of the curriculum had a small positive effect on the math scores of children at the end of the year.

Discussion

We consider several sets of questions concerning the effectiveness of the programs and what can be learned from the evaluations of them. We conclude with suggestions for a research agenda.

Questions Concerning the Current Programs

How successful are the programs? A basic finding is that math education, as exemplified by the programs described above, can "work" for young children. Studies of different curricula find relatively large effect sizes, as indicated above. They were at least fairly successful in accomplishing their various and sometimes diverse goals. There is little doubt that early education can promote early mathematics learning in different areas, including number, shape, space, and pattern. This is valuable information, and it gets the enterprise started: there should be no doubt that early childhood mathematics education can be effective, at least in the short term.

At the same time, there are many questions remaining to be addressed and much that still needs to be learned. One question refers to the differential effectiveness of the programs under consideration. Do some achieve better results than do others? The answer is probably yes, but it is hard to compare programs directly. As we showed, the research studies used a wide variety of outcome measures for evaluation. As a result, it is hard to examine the relative effectiveness of programs (even using effect size) when they are trying to accomplish different goals. One program may be effective in promoting spatial reasoning and another effective in teaching the reading of numerals. It is good that both are effective, but it is hard to compare programs when goals and subject matter differ.

Further, it is important to note that many evaluations use outcome measures developed in conjunction with the goals of the curriculum (e.g., *PreK Math/DLM*), whereas other programs (e.g., *BMLK*) use measures that do not align with the curriculum itself. In a sense, the aligned outcome measures can be considered near transfer tasks and standardized measures, far transfer tasks. The use of an outcome measure that aligns with the curriculum increases the likelihood that the evaluation will find positive effects, but does not indicate whether the treatment group would perform better on mathematical topics not emphasized in the curriculum. The use of far transfer tasks can provide insight into general aspects of learning but provide little useful detail about the specifics. Each approach has strengths and limitations that need to be recognized.

We also need to be clear about the inevitable limitations of the various outcome measures. Although most have reasonably sound psychometric properties, it is fair to say that of necessity the measures generally focus on relatively easy to measure aspects of performance. The results of such an approach are valuable in establishing that some learning has occurred, but the approach often fails to illuminate that learning in any detail. It is conceivable, of course, that a curriculum "works," in the sense of promoting high test scores on these kinds of evaluations, but that it does not promote thinking or enhance long-term motivation for learning mathematics. It is conceivable that teachers may teach to the evaluation and in the process fail to promote meaningful learning. High stakes assessment may have negative effects at the preK and kindergarten levels, just as it does at higher levels of education.

How successful are the programs at teaching various topics within the mathematics curriculum? Mathematics is a complex subject, even in preschool. It involves far more than teaching rote aspects of number. The discipline is both wide and deep (Ginsburg & Ertle, 2008), and includes topics ranging from the invariance of cardinal number across various transformations to the idea of mapping physical space. Following the advice of the NAEYC/NCTM, many of the curricula present mathematics as a broad array of topics, including number, measurement, space, shape and pattern. At the same time, the program evaluations generally present little information concerning children's learning in each of these specific areas. Consequently, we need to know much more about program effectiveness in teaching the very different topics of mathematics, ranging from number to shape and pattern.

In particular, we need to learn much more about a very special topic, namely mathematical thinking and reasoning. Children need to learn to understand why a figure is a triangle, not a rectangle, and to reason about why one operation (like 2 + 3) yields the same result as another (like 3 + 2). Some of the programs seem to promote such mathematical thinking and reasoning, but in general, the evaluations do not attempt provide in depth information concerning thinking and reasoning processes, strategies employed, and understanding of important ideas. One reason is that random assignment studies involving large numbers of children need to employ tests that are easy to administer on a large scale and relatively short. Such tests, although useful for their purpose, are not optimal for measuring cognitive phenomena as subtle and complex as reasoning and understanding. Another reason is that the field lacks appropriate and practical measures of mathematical thinking and reasoning.

In brief, we need to know much more than that a program "works." We need to know how it works in the different substantive areas of mathematics, and how it works in the key area of mathematical thinking and reasoning. This kind of information can be of great value for researchers, teachers, and curriculum developers alike.

What aspects of the programs' pedagogical methods or materials are most powerful in promoting children's mathematical learning? The programs employ various methods and materials. Sometimes they use small groups, and sometimes the use large ones. Sometimes the approach is relatively didactic and sometimes more open-ended. Sometimes they use games, and sometimes stories. Sometimes they use computers, and sometime they do not. Sometimes they do mathematics as a stand-alone activity, and sometimes it is integrated into other activities.

There are many questions to ask about these practices. How effective are the various methods—games, manipulative, stories, and the like, under various circumstances? How should the various methods be used in presenting the material? These of course are the primary issues of interest to teachers who work every day on teaching mathematics.

A crucial set of questions revolves around teaching. Many of the studies attempt to ensure the fidelity of instruction, in the sense of determining whether teachers teach the material more or less as intended. But the studies pay very little, if any, attention to the ways in which teachers implement the activities, incorporate them into their own teaching styles, find some topics easier to teach than others, interpret the materials, adjust teaching to meet student needs, and understand (or misunderstand) the competence of their students. Teachers are at the heart of any program and curriculum, yet the present studies tell us little about their roles in the enterprise.

In general, because of their broad focus on student outcomes, the evaluations typically provide no information about the strengths and weaknesses of various aspects of the programs, or about intentional teaching. As a consequence, the questions about methods, materials and teaching—the questions of most interest to teachers (and creators of professional development programs)—remain unanswered.

What have we learned about group, individual, and developmental differences in children's mathematics learning? There are substantial differences between SES groups in mathematics achievement. As is well known, low SES children generally perform more poorly than their middle SES peers. It appears that preschool instruction can be effective for both groups, although it may not eliminate the initial gap between them. But it is important to know whether, how, and to what extent the groups differ in their reactions to and learning from various programs. How do the different groups of children interact with the teachers and activities and does that contribute to the outcomes?

There are also wide individual differences in preschool children's psychological functioning, language and mathematical knowledge. Some children enter preschool knowing little English. Some have poor executive function. Some may be stronger than others in number (Dowker, 2005). It is conceivable that some children may benefit more than others from a particular pedagogical method or curriculum.

Similarly, there may be important developmental differences in learning mathematics. The old view that preschoolers in general are "concrete" thinkers, or "preoperational" and therefore cannot learn an abstract subject like mathematics has been discredited. Nevertheless, there may be important differences between typical 3-year-olds and 4-year-olds in their learning of mathematics. What is the nature of these differences?

In general, the evaluation studies, focused as they are on the measurement of broad outcomes, do not provide information useful for addressing issues of group, individual or developmental differences in learning mathematics.

What can we conclude about effectiveness? The evaluation research has shown that the various programs are effective in varying degrees in achieving their varied goals. That is important to know, but the research tells us little more than that, perhaps in part because of the very nature and demands of large-scale random assignment research. The research has little to say about relative effectiveness of different programs, about their success in teaching specific topics, about the relative power of different pedagogical techniques and materials, about how teachers teach, and about group, individual and developmental differences in learning.

A Research Agenda

The current evaluation paradigm has taught us a great deal, and has taken a useful first step in the direction of sound early childhood mathematics education. Yet, as we have shown, the paradigm is limited in its ability to answer key questions. The productive solution is not simply more and bigger RCT studies. Instead, we need a new and wide research agenda dealing with several issues fundamental to early mathematics education.

What and how should we evaluate? One set of issues concerns further evaluation of mathematics programs. Now that we know that many of them work, it is important to conduct research targeted to more specific issues, like the relative effectiveness of different kinds of programs for teaching specific content. What are some effective ways for teaching 4-year-olds the analysis of geometric forms or 3-year-olds some fundamental properties of number? How effective are particular materials or pedagogical methods?

In conducting work of this type, the field can benefit from improved outcome measures that tap into essential aspects of learning across the various topics that comprise the content of early mathematics. We need to get beyond using measures because they are convenient or have sound internal or test-retest reliability. The fundamental question is whether they measure what is important to measure. Fortunately, NIH is now funding the development of new research based measures of mathematics knowledge and other topics relevant to early childhood.

And as we go forward, here's a topic that should not receive much research attention: the long-term effects of early mathematics curriculum. Children's later mathematics outcomes must be influenced by the education children receive after preschool. We know that much of that education, particularly for poor children is lacking, with the likely result that children receiving good preschool math education may not do very well later in school. This outcome is entirely to be expected and does not reflect on the children's abilities or what is possible to achieve. Hence not much effort need be put into studying it. A more effective approach is to work at improving and evaluating education at all levels.

What are the processes involved in mathematical teaching and learning? A second set of issues revolves around the processes of teaching and learning. Mathematics has seldom been taught at the early childhood level. Consequently we know little about how to teach it or how children learn it. Most of the cognitive developmental research that has provided a revolution in the way we conceptualize young children's mathematical abilities does not focus at all on teaching or on how children learn from teaching and in an educational context. The various curricula are "research-based" mostly in the sense that they are inspired by research on children's mathematical competence, and not in the sense that they derive from the research any particular guidance on how to present or teach any topic. Therefore, we need research, some of which needs to be exploratory, that focuses on teaching and on children's learning from teaching in an organized setting. Because so little is known about these topics, this kind of research will ultimately be of great practical value to teachers. By contrast, current evaluation research does not speak to teachers about these issues, except to tell them that effective early math education is possible.

How can we effectively implement math curricula? Many early childhood teachers have no interest in early mathematics, fear it, and do not want to teach it, sometimes because of outmoded notions of developmental appropriateness. School districts, preschools, and childcare organizations typically give the teachers little help in their efforts to implement mathematics programs. Several questions then arise: What are the obstacles that stand in the way of successful implementation? How can they be overcome? How can one help teachers to cope with their fears of mathematics and learn effective teaching methods (assuming we learn what those are)? What kind of supports—especially professional development—do teachers need over the long term to implement early mathematics education? In general, the problem is first to set up and then examine the effectiveness of an infrastructure for promoting early mathematics education. In the end, everything boils down to helping and supporting teachers to do good work over the long term.

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Table 1. Mathematics Domains Covered by Each Curriculum

Program	Ages	Number	Shape Geometry	Measurement	Pattern	Sorting Sequencing	Logic	Spatial	Data
Big Math for Little Kids	PreK & K	X	X	X	X		X	X	
Building Blocks	PreK through Grade 2	X	X	X	X	X			X
Pre-K Mathematics	PreK	X	X	X	X	X	X		
Children's School Success	PreK	*not reported*							
Sophian's Curriculum	3 & 4 year olds	X	X	X		X			
'Round the Rug Math	PreK through Grade 2	X	X	X	X			X	X

Table 2. Comparison of Curriculum Evaluation Studies

Program	Research Funding	Study Type	Sample	Control Condition(s)	Measure	Effect Size[4]
Big Math for Little Kids	IES Research Grant	RCT	Treatment • 16 preK classrooms • 10 K classrooms Control 16 preK classrooms 10 K classrooms	Prevailing curriculum (e.g., Creative Curriculum, "home grown" curriculum)	ECLS-B Mathematics	.43
Building Blocks (BB)	NSF	RCT	BB • 8 classrooms PMC • 7 classrooms Control • 8 classrooms	PreK Math or Prevailing curriculum (e.g., Creative Curriculum, Montesorri, "home grown")	Early Mathematics Assessment (EMA)	BB vs. *PreK Math*: .47 BB vs. Control: 1.07
Pre-Kindergarten Mathematics Curriculum with DLM Express Software	PCER	RCT	Treatment • 20 classrooms Control • 20 classrooms	Prevailing curriculum (e.g., Creative Curriculum, Montesorri, High/Scope, "home grown")	Child Mathematics Assessment (CMA)	.55
Children's School Success	ICSR	RCT	*not reported*	*not reported*	Woodcock Johnson (WJ), subtest 10 and 18	*not reported*

[4] All mathematics curricula reviewed except for Children's School Success reported a positive statistically significant impact on children's mathematics knowledge.

Additional Information on Mathematics Curricula Reviewed by Ginsburg, Lewis, & Clements

Big Math for Little Kids

The Big Math for Little Kids (*BMLK*) is a mathematics curriculum designed to facilitate mathematics learning for pre-kindergarten and kindergarten students (Greenes, Ginsburg, & Balfanz, 2004). The program includes six units (number, shape, measurement, constructing and partitioning numbers, patterns and logic, and navigation and spatial concepts) containing a sequence of enjoyable activities designed to promote both mathematical understanding and language (Greenes, et al., 2004). The program is designed to be used in whole-class and small-group settings, as well as with individual students. Early field-testing suggested that children taught using the curriculum achieved a high level of mathematical understanding, learned to count to high numbers, were able to take the perspective of others, and anticipated further events and predicted outcomes (Greenes et al., 2004).

The effectiveness of the curriculum has been examined using a two-year randomized controlled trial (RCT) that was funded by the US Department of Education Institute of Education Sciences. The study, which focused on low-income children attending subsidized child care centers in New York City for pre-kindergarten and kindergarten, compared the mathematics achievement of children whose teachers either used the *BMLK* curriculum or continued to teach mathematics using the Creative Curriculum (Dodge, Colker, & Heroman, 2002) or a home grown early childhood curriculum. The treatment teachers attended monthly workshops to deepen their understanding of young children's mathematical learning, as well as to demonstrate important components of the curriculum.

Student achievement was assessed using the mathematics assessment developed for the Early Childhood Longitudinal Study, Birth Cohort (ECLS-B; National Center for Education Statistics) at the beginning and end of their pre-kindergarten year and then again in kindergarten, yielding scores at four time points. The advantage of using the ECLS-B is that it is (1) nationally normed and standardized and (2) that the assessment is not directly aligned with the content of the intervention, providing a stricter test of impact. The norming was conducted using a large stratified random sample including 14,000 children born in 2001 and the measure has high internal reliability (Rock & Pollock, 2002). The test itself is adaptive, meaning that the accuracy of responses determine whether the test taker receives easier or more difficult items, and allows for precise estimation of ability with fewer administered questions.

Preliminary results, using latent growth modeling, are currently available for this study and suggest that children in the *BMLK* group demonstrate a larger increase in mathematics achievement compared to children in the control group. There were no significant differences between the two groups at the beginning of the study, but by the end of kindergarten these differences emerge with a medium effect size (Cohen's d=.43). It should be noted that this study was conducted by the authors of this paper (Clements, Lewis, and Ginsburg, 2008).

Building Blocks

The *Building Blocks* (funded by the National Science Foundation) mathematics curriculum, designed for pre-kindergarten through 2nd grade children, is designed specifically to develop competencies detailed in the National Council of Teachers of Mathematics "Principals and Standards for School Mathematics" (Sarama, 2004). To this end, the curriculum focuses on developing spatial and geometric competencies, as well as numeric and quantitative concepts (Sarama & Clements, 2004). Within these two areas, three mathematical themes are integrated including patterns, data, and sorting and sequencing (Sarama, 2004). In addition to classroom activities, the curriculum relies heavily on the use of computer software, designed as part of the curriculum, to meaningfully engage children as young as 3 years of age in mathematical concepts (Sarama, 2004; Clements & Sarama, 2003). As a result, teachers are required to provide guidance within and between formats.

A randomized controlled trial (RCT) was conducted, comparing three groups of teachers, namely a group using the *Building Blocks* Curriculum, a second group using the Pre-Kindergarten Mathematics Curriculum (PreK Math; Klein, Starkey, & Ramirez, 2002), and a third control group that experienced whatever teaching was involved in "business as usual". These groups included equal numbers of classrooms, some serving low-income students only and other classrooms serving both low-income and middle-income students.

Researchers assessed the impact of the three mathematics curricula using a measure of mathematics ability that was constructed by Clements and Sarama and includes many of the same mathematics activities that are part of the *Building Blocks* curriculum. The Early Mathematics Assessment (EMA) is administered individually to children during two 10-20 minute interviews, which include detailed protocol, coding, and scoring for the interviewer to follow (Clements & Sarama, 2008). In this study, the interviews were videotaped and recoded to ensure reliability. EMA is a comprehensive assessment of mathematical knowledge, is not aligned with any particular curriculum, and is has high internal reliability (Clements & Sarama, 2008).

Results showed that both the *Building Blocks* and *PreK Math* curriculum groups performed significantly better on the EMA measure than the control group and the *Building Blocks* group performed significantly better than the *PreK Math* intervention group (Clements & Sarama, 2008). *Building Blocks* outperformed the control group with a large effect size of 1.07 and outperformed the *PreK Math* curriculum with a medium effect size of .47. The Pre-Kindergarten Mathematics Curriculum outperformed the control group with a medium effect size of .64. Overall, the program effects for *Building Blocks* were the same regardless of program type (i.e., Head Start or a state-funded program), classroom socioeconomic (SES) composition, and child-level SES. In other words, there was no evidence that the impact of *Building Blocks* varied for different groups of students.

In addition to the impact of the curricula on the composite scores, subscore analyses demonstrated that some skills benefited more from *Building Blocks* than *PreK Math* (count higher without committing errors, describing counting errors, and explaining how to correct counting errors), while for other skills the *Building Blocks* and *PreK Math* students performed equally as well (object counting, verbal counting, comparing numbers, sequencing, shape identification and representation, and identifying counting errors) (Clements & Sarama, 2008).

Pre-Kindergarten Mathematics Curriculum

The Pre-Kindergarten Mathematics Curriculum (PreK Math), originally designed as part of the Berkeley Math Readiness Project has been evaluated as part of the Preschool Curriculum Evaluation Research (PCER) Program. *PreK Math*, was developed for children in grades [XX through XX] (Klein & Starkey, 2004). The curriculum is organized around seven units: enumeration and number sense, arithmetic reasoning, spatial sense, geometric reasoning, pattern sense and unit construction, nonstandard measurement, and logical reasoning. The small-group activities included in the curriculum use concrete materials and are designed to improve mathematical knowledge, specifically numerical and spatial-geometric thinking (Klein & Starkey, 2004).

An effectiveness study compared children in equivalent numbers of low- and middle-income classrooms using *PreK Math* to a comparison group (Klein & Starkey, 2004). Both income levels were included in order to test the researchers' hypothesis that because the curriculum provides experiences to low-income children that middle-income children were likely to receive at home, the impact of *PreK Math* would be more pronounced among low-income children (Starkey, Klein, & Wakely, 2004). In addition to classroom activities, the authors of *PreK Math* developed a home component of the curriculum, which includes parent classes three times per year designed to teach parents how to use the activities with their children (Starkey, Klein, & Wakely, 2004).

Researchers administered the Child Math Assessment (CMA; Klein & Starkey, 2004; Starkey, Klein, & Wakely, 2004) to both groups of students in the fall and spring of their PreK year. The CMA assesses a wide variety of mathematical concepts using 16 separate tasks, which are administered in two 20-30 minute individual testing sessions. For this study, the assessments were videotaped and coded for reliability (Starkey, Klein, & Wakely, 2004). Half of the children received the first section during the first testing session and the other half received the second section of the test during the first testing session.

The results demonstrated that that mathematics ability for middle-income children in both study groups was significantly higher than that of their low-income peers, and that their mathematics ability grew at a faster rate over the course of the study (Klein & Starkey, 2004). The results also indicated that there was a significant main effect for *PreK Math*, with the intervention group having significantly higher CMA scores. The researchers conclude that while *PreK Math* was effective for both low- and middle-income children, it was particularly beneficial to the low-income students (Klein & Starkey, 2004; Starkey, Klein, & Wakely, 2004).

Researchers conducted a second study (also involving random assignment of classrooms) of *PreK Math* in two early childcare settings—Head Start and state-funded preschools—representing 40 pre-kindergarten classrooms (Klein, et al., in press). Teachers in the treatment group implemented *PreK Math* and the DLM Early Childhood Express Math software (Clements & Sarama, 2003), part of the *Building Blocks* curriculum, while the control group continued their regular curriculum, which included Creative Curriculum, High Scope, Montessori, and other local curricula (Klein, et. al., in press). As in the study described above, the children were assessed using the Child Math Assessment (CMA) and coded from videotapes. As, expected, the math scores of the *PreK Math/DLM* and control groups did not differ between groups in the fall, but by spring the intervention group scored significantly higher than the comparison groups with a medium effect size of .55 (Klein, et. al., in press). This study used a second mathematics outcome measure; this composite score consisted of the CMA, a Shape Compositions task, and the Woodcock Johnson Applied Problems score. Analyses using the composite score also demonstrated a significant difference between the treatment and control groups with an effect size of .62 (Klein, et. al., in press).

Children's School Success (ISRC)

The Children's School Success (CSS) Program is a comprehensive curriculum for preschool children implemented with at-risk children (low income families, students with disabilities, and/or ELL), which focuses on oral language and literacy, science, math, and social competence (Lieber, et. al., 2007). The program views young children as "active, self-motivated learners" and includes student choice, family involvement and individualization into the program's conceptual framework (Odom, et. al., 2007b). The curriculum utilizes "linked learning", or activities that build upon the previous lesson's content, integrates curricular domains across activities, includes a problem solving process, and capitalizes on children's interests and experiences (Odom, et. al., 2007b). The mathematics aspect of the program was adapted from Douglas Clements' *Building Blocks* curriculum and includes number and operations, geometry and spatial sense, measurement, pattern/algebraic thinking, and displaying and analyzing data (Odom, et. al., 2007b).

Three years of research was conducted with approximately 800 at-risk children in Head Start or state pre-k or private childcare centers, in which the majority of enrolled children were of Caucasian/Non-Hispanic dissent (Odom, et. al., 2007b). Student achievement was measured used the Woodcock Johnson Math Subtest. Although the authors did not provide information on the characteristics of the math subtest, a study conducted by the NICHD Early Child Care Research Network (2002) found that the Woodcock Johnson Applied Problems subtest has an internal consistency of .91. This assessment does not align directly with the curriculum itself and as such is less biased in favor of the curriculum.

Presentations on the research have not included analyses comparing the treatment and control groups. Instead, the focus of the presentations thus far has been on the impact of treatment fidelity on children's assessment scores, as well as their initial ability levels. These presentations have presented analyses that show that treatment fidelity has a positive significant association with children's post test scores (after controlling for their pretest scores) on many (but not all) of the outcome measures. The presentations have also shown that, not surprisingly, children with lower test scores at the beginning of the study learned more in high fidelity classrooms than initially low-achieving children in low-fidelity classrooms. The lack of research findings regarding the treatment and control group comparisons, combined with the focus on treatment fidelity in the majority of research conference presentations leads us to wonder whether the evaluation of the CSS curriculum model did not find a significant difference in the treatment and control children on study outcome measures.

'Round the Rug Math: Adventures in Problem Solving

'Round the Rug Math: Adventures in Problem Solving is a supplementary program for pre-K through 2nd grade classrooms that uses stories to teach problem-solving (Casey, 2004; Casey, Kersh, & Young, 2004). This approach teaches mathematics concepts within a language rich medium that extends over the course of many lessons (Casey, 2004). The program specifically focuses on spatial and analytical skills, which can help address learning gaps, so it is not meant to be a comprehensive curriculum (Clements & Sarama, 2008). However, the focus on developing spatial skills is also intended to achieve equity between girls and boys, who consistently show better spatial and geometry skills (Casey, 2004). The program does two things simultaneously: (1) integrates mathematical content into the theme-based approach generally used throughout early childhood curricula, and (2) teaches mathematics content systematically with sequenced lessons (Casey, Kersh, & Young, 2004). Specifically, the 'Round the Rug Math curriculum teachers mathematical concepts in a "systematic, hierarchical progression" through the use of long epic stories, which allow characters to have multiple adventures the expose students to mathematical problems or concepts (Casey, Kersh, & Young, 2004). Students must solve the problem before going on to the next part of the story, which includes progressively more difficult concepts.

In the first evaluation of the effectiveness of one story on students' geometric understanding was conducted with Kindergarten students, comparing the 'Round the Rug Math curriculum to a control group. The initial results indicate that the students who learned the content with the storybook approach improved significantly more than students who learned the content without the storybook approach, although details what this control group received were not described (Casey, Kersh, & Young, 2004). However, no information on the outcome measure or any statistical information was provided on this study.

A second study comparing the effectiveness of the program by gender suggests that in Kindergarten girls benefit more than boys from learning the mathematical content in a storytelling format (Casey, Erkut, Cedar, & Young, 2008). In this experimental study, six kindergarten teachers were randomly assigned to either the treatment or control group, with 76 students in the treatment group and 79 students in the control group. Two measures were used for pre- and post-test, including Triangles subtest of the Kaufman Assessment Battery for Children (K-ABC) and the Tangram test (Casey, Erkut, Cedar, & Young, 2008). The overall reliability of the K-ABC using a split-half procedure is .86-.93, with the Triangles subtest's factorial loading at .70 for boys and .76 for girls (Casey, Erkut, Cedar, & Young, 2008).

There were higher pretest scores for the intervention group on the Triangle test, but no differences on the Tangram test. For the Triangle test, a repeated measures ANOVA showed a significant improvement from pretest to posttest ($p<.001$), as well as a significant difference between the treatment and control group ($p<.003$), particularly for the girls ($p<.001$; partial $eta^2 =.141$). A comparison of the boys by condition did not yield a significant difference (Casey, Erkut, Cedar, & Young, 2008). For the Tangram test, a repeated measures ANOVA showed a significant improvement from pretest to posttest ($p<.001$), but no other effects.

Mathematics Curriculum Developed by C. Sophian

Sophian (2004a) differentiates the "developmentally appropriate curriculum" as one that matches the cognitive abilities of the learner from what she coined the "prospective developmental perspective", meaning that some mathematical skills are important for learning at a later developmental point. This is often the unspoken goal of early education: teaching students enough so that they are ready and able to learn effectively in later grades and for low-income children the hope is that this preparation closes the achievement gap (Sophian, 2004b). While the development of social competence has long been a goal of Head Start, recent trends in accountability have broadened the focus of early childhood educators generally, and Head Start specifically, to include reading and math skills needed for school success (Fantuzzo, et. al., 2007). In addition, research suggests that low-income children, such as those in Head Start, have less mathematical understanding compared to wealthier counterparts (Sophian, 2004b).

Sophian developed a mathematics curriculum specifically for 3- and 4- year old children attending Head Start centers, which focuses heavily on measurement, object properties, and geometry (Sophian, 2004b). The curriculum is meant to be integrated within the rest of the Head Start program rather than as a stand alone curriculum. The curriculum was organized into weekly project activities and parents and teachers were given specific activities to complete with the children.

There is great emphasis on combining shapes in new ways and measurement with various units (Sophian, 2004b). Specifically, Sophian (2004b) describes the program as exploring the relationships between shapes rather than identifying features of those shapes (i.e. number of sides or angles). Rather than including measurement as a separate unit within the curriculum, Sophian (2004b) used measurement throughout the curriculum with a specific focus on measuring the same objects with different units of measurement; something she claims is not present in other similar programs.

An evaluation of the program was conduced to determine whether this math program could improve the readiness of low-income young children. Specifically, three Head Start centers, two classrooms within each center, served in the treatment group. Then six Head Start centers were matched on center characteristics and served in the control group; three centers conducted a literacy intervention and three centers continued their regular curriculum (Sophian, 2004b). In this case, the treatment group was provided the mathematics curriculum while the comparison group received either a literacy curriculum or no intervention (i.e. "business as usual" group). Children were assessed in the fall and spring of their pre-K year using an assessment procedure intended to align closely with the curriculum: the Developing Skills Checklist (DSC) and a supplemental measure developed for the study. The mathematics portion of the DSC assesses:

> naming shapes, reproducing and extending patterns, counting, identifying numerals, matching sets and numerals, joining and separating sets, identifying original positions, and logically operations (classification, conservation of number, estimation, and seriation) (Sophian, 2004b, pp. 69).

Using the DSC score, the mathematics intervention group scored significantly higher than either the literacy intervention group or the no-intervention group and there was a significant difference between conditions, using pretest scores as covariates, with an effect size (partial η^2=0.092; Sophian, 2004b). The supplemental score also showed the mathematics group scored significantly higher and there was a significant effect for the mathematics intervention (partial η^2=0.083).