Research Narrative

1.0 Contribution of Project to Solving an Education Problem

National and international assessments of U.S. students’ achievement in mathematics “evoke both a sense of despair and of hope” (Lemke et al., 2004; National Research Council [NRC], 2001, p. 55). The mathematical underachievement of students in the United States is well documented. Results of the 1999 Third International Mathematics and Science Study (TIMSS) indicate that by eighth grade U.S. students’ mathematics performance is below the international average, particularly in more advanced math (National Center for Education Statistics [NCES], 2003; Schmidt, 2002). For example, US students performed below the international average on geometry, measurement, and proportionality (NRC, 2001). The National Assessment of Education Progress (NAEP, 2003) results parallel the findings of international comparisons.

The problem of underachievement is particularly severe for students with disabilities, limited-English proficient (LEP) students, students from impoverished backgrounds, and minorities (NCES, 2003; NRC, 2001). Factors such as low expectations, difficulty applying mathematical skills in flexible ways to solve novel problems (Goodman, 1995), deficiencies in mathematical concepts, inadequate instruction by teachers who have a poor grasp of mathematics, overemphasis on procedural knowledge, and lack of opportunities to achieve at high levels are known to contribute to these students’ poor mathematics achievement (Schmidt, 2002). Many teachers lack specific instructional strategies to help these children meet the high standards (Ma, 1999). Although there is emerging evidence to support reform based mathematics methods and curricula (Cohen & Hill, 2001; Fuson, Carroll, & Drueck, 2000; Schoenfeld, 2002), data regarding the effects of mathematics reforms on learning for students at-risk for math failure are limited (Baxter, Woodward, Voorhies, & Wong, 2002). Furthermore, findings from a recent meta-analysis of intervention research in mathematics for low achieving students indicated that few studies focused on specific instructional practices to improve student learning (Baker, Gersten, & Lee, 2000). Evidently, the need for a research-based model that articulates how mathematics is taught to students with learning difficulties is critical at the present time.

The proposed three-year study will meet Goal 2 requirements in that we will develop and evaluate the efficacy of a mathematics problem solving intervention designed to address the instructional needs of a wide range of Grade 6 learners, but with particular emphasis on addressing the needs of low achieving students. The basic premise of our study is that middle school mathematics problem solving instruction should focus on critical concepts (e.g., ratios, proportions) and relations (e.g., multiplication and division) needed to understand mathematics content and solve a range of problems encountered in everyday life. Although many students have learned to compute answers when solving mathematical problems in this topic area, they may not necessarily understand the procedures or monitor their understanding to effectively solve novel problems. The proposed intervention is designed to enhance students’ mathematical thinking in solving contextual problems involving ratios and proportions, topics that have been shown to be quite challenging for children and adolescents (e.g., Fujimura, 2001). Specifically, we will develop a set of lessons to promote students’ understanding of problems involving multiplicative relations using schema-based instruction (SBI), which is known to promote meaningful learning (retention as well as transfer of problem solving).

We propose a project with three primary foci conducted across three years. The primary focus of Year 1 is the development of an instructional approach (SBI and SBI plus self-monitoring; SBI-SM) targeting problem-solving skills involving multiplicative relationships for
Grade 6 students using a design experiment (The Design-Based Research Collective, 2003). In Year 2, the major objective is the formal evaluation of the impact of SBI or SBI-SM on sixth graders’ problem solving performance. We will conduct an experimental study with teachers randomly assigned to experimental and control conditions. The major focus of Year 3 is to supplement the SBI and SBI-SM intervention with a manipulation of instructional intensity (e.g., ad hoc small group tutoring) that is known to moderate learning outcomes for students who are at-risk for math difficulties.

**Conceptual Framework Underlying the Proposed Research**

The conceptual framework for the proposed research is based on the integration of two major lines of research related to teaching and learning mathematics: Use of schema theory to highlight the role of mathematical structure in problem-solving, and the role of metacognitive skills in successful problem solving.

**Schema Theory and Successful Problem Solving**

The *Principles and Standards for School Mathematics* developed by the National Council of Teachers of Mathematics (NCTM, 2000) emphasize the importance of problem based mathematics instruction. Mathematical problem solving refers to “the cognitive process of figuring out how to solve a mathematics problem that one does not already know how to solve” (Mayer & Hegarty, 1996, p. 31). In school mathematics curricula, story problems that range from simple to complex problems represent “the most common form of problem solving” (Jonassen, 2003, p. 267). Problem solving is vital because of its importance in daily life. It provides the context for “learning new concepts and for practicing learned skills” (NRC, 2001, p. 421).

Improving students’ problem solving skills has proved to be a significant challenge. Although recent research with high school students indicates that formal symbolic problems are more difficult than story problems or word equations (Koedinger & Nathan, 2004; Nathan & Koedinger, 2000), research with elementary and middle school children indicates that mathematical tasks that involve story context problems are much more challenging than no-context problems (Cummins, Kintsch, Reusser, & Weimer, 1988; Mayer, Lewis, & Hegarty, 1992; Nathan, Long, & Alibali, 2002; Rittle-Johnson & McMullen, 2004). Solving story problems requires the integration of several cognitive processes that are difficult for young children and many middle school students, such as the low performing sixth graders in this project, because of reading problems, an insufficient knowledge base, or limited working memory capacity (Jordan, Kaplan, & Hanich, 2002; Swanson & Beebe-Frankenberger, 2004). When solving story problems, children need to understand the language and factual information in the problem, translate the problem using relevant information to create an adequate mental representation, devise and monitor a solution plan, and execute adequate procedural calculations (Desoete, Roeyers, & De Clercq, 2003; Mayer, 1999). In short, solving word problems is closely related to comprehension of the relations and goals in the problem (e.g., Briars & Larkin, 1984; Cummins, et al., 1988; De Corte, Verschaffel, & De Win, 1985; Kintsch & Greeno, 1985; Riley, Greeno, & Heller, 1983). Despite their difficulty, story problems are critical in helping children connect different meanings, interpretations, and relationships to the mathematical operations (Van de Walle, 2004).

The NCTM Standards, as well as NSF-funded reform curricula, advocate a student-centered, guided discovery approach for teaching students problem solving (Mayer, 2004; NRC, 2001). However, recommendations for this kind of instructional approach are at odds with the literature
on problem solving instruction for students at risk for math difficulties. These students benefit far more from direct instruction and practice at problem solving than competent problem solvers (Baker et al., 2001; Jitendra & Xin, 1997; Tuovinen & Sweller, 1999; Xin & Jitendra, 1999). In fact, research conducted in reform-oriented classrooms indicates that students with learning disabilities assume passive roles, encounter difficulties with the cognitive load of the activities and curricular materials, and their progress is substantially below that of their nondisabled peers (Baxter, Woodward, & Olson, 2001; Baxter et al., 2002; Woodward & Baxter, 1997). Therefore, one of the main components of our proposed problem solving instructional program is explicit instruction in modeling problem solving strategies using visual (schematic) representations.

However, it is critical to note that, despite the focus of the present intervention on direct instruction, the literature is quite clear that not all methods of direct instruction on problem solving strategies are equally effective with students with learning disabilities (Montague, Applegate, & Marquard, 1993). One weakness of many texts that adopt a direct instruction approach is that these texts are organized in a way that the same procedure (e.g., multiplication) is used to solve all problems on a page. As such, students do not have the opportunity to discriminate among different types of problems. A second weakness is that many forms of conventional problem solving instruction teach students to use key words (e.g., in all suggests addition, left suggests subtraction, share suggest division, Lester, Garofalo, & Kroll, 1989) and mechanical procedures (e.g., “cross multiply”) that do not develop conceptual understanding. These key word approaches ignore the meaning and structure of the problem and fail to develop reasoning and making sense of story situations (Van de Walle, 2004).

An approach to teaching problem solving that relies on direct instruction but addresses the two weaknesses identified above emphasizes the role of the mathematical structure of problems. From schema theory, it appears that cognizance of the role of the mathematical structure (semantic structure) of a problem is critical to successful problem solution (Sweller, Chandler, Tierney, & Cooper, 1990). Schemas are domain or context specific knowledge structures that organize knowledge and help the learner categorize various problem types to determine the most appropriate actions needed to solve the problem (Chen, 1999; Sweller et al., 1990). For example, organizing problems on the basis of structural features (e.g., rate problem, compare problem) rather than surface features (i.e., the problem’s cover story) can evoke the appropriate solution strategy. In sum, schemas are the basis for understanding and the appropriate mechanism to “capture both the patterns of relationships as well as their linkages to operations” (Marshall, 1995, p. 67). A distinctive feature of schemas is that when one piece of information is retrieved from memory during problem solving, other connected pieces of information will be activated. Thus, schema theory suggests that problem-solving instruction should focus students’ attention on the underlying mathematical structure of problems.

In terms of underlying mathematical structure, arithmetic problems are separated into two large categories, additive and multiplicative structures. Given the focus of our instructional program on ratio and proportion problems, multiplicative structures (i.e., problem situations involving multiplication and division) are most relevant (Vergnaud, 1983). Multiplicative situations can be classified as equal-groups, rate (involving proportion structure), compare, rectangular-area, and Cartesian-product (Greer, 1992; Schmidt & Weiser, 1995). Two problem types, multiplicative compare and vary (e.g., equal-groups, rate) characterize most multiplication and division problems presented in commercial mathematics programs (Marshall, Pribe, & Smith, 1987; Marshall, Barthuli, Brewer, & Rose, 1989; Marshall, 1990; Van de Walle, 2004).
- A **multiplicative compare** problem consists of two different sets (compared and referent) and includes a relational statement that relates the compared set to the referent set. Typically, the multiplicative compare problem describes and expresses the compared set as a multiple ($n$ times as much as) or part ($n^{th}$ multiple of) of the referent set. (For an example of this problem type, see Appendix B, p. 3)

- A **vary** problem describes an association (ratio) between two things (i.e., subject and object). It consists of two pairs of associations. The numerical association across the two pairs is constant. Typically, the vary problem involves an “if…then” relationship. The “if” statement declares a rate or unit ratio in one pair, and the “then” statement describes the variation (enlargement or decrement) of the two quantities in the second pair. (For an example of this problem type, see Appendix B, p. 5)

There is growing evidence regarding the benefits of schema training that focuses on priming the problem structure. Two studies (Quilici & Mayer, 1996; Tookey, 1994) with college students demonstrated that schema training or schema induction instruction enhances mathematical problem solving, especially for low-ability students compared to high-ability students. Quilici and Mayer (1996), for example, used statistic problems to examine how grouping tasks on the basis of structure ($t$ test, correlation, chi-square) facilitates schema development. Schema induction was stronger for students who studied independently using problems grouped by structural features than those who studied with surface-emphasizing (i.e., the problem’s cover story) examples. This pattern was strongest for lower ability students, who typically tend to focus on surface features than higher ability students unless instructed specifically. However, these studies did not address how to promote mathematical problem solving for school aged children at risk for math difficulties. Recent research with school-aged children shows promise for SBI. Using a series of water jar problems, Chen’s (1999) work with elementary school children demonstrated that variant procedural features were more likely than invariant procedural features in facilitating schema induction and effective problem solving. However, this study did not include students at risk for mathematical difficulties. One issue not addressed by the above studies is whether children at risk for math difficulties are able to evoke the schemas without explicit instruction.

The research on problem solving conducted by Fuchs and colleagues (e.g., Fuchs, Fuchs, Prentice et al., 2003; Fuchs, Fuchs, Finelli, Courey, & Hamlet, 2004) is important, because their findings demonstrated that teacher-directed instruction in schema induction and self-regulated learning strategies enhance third graders’ (low, average, and high achievers) ability to solve mathematical problems. These researchers systematically examined the effectiveness of schema-inducing instruction that emphasized how superficial features (e.g., different format, different question) make familiar problems novel “without modifying the problem type or the required solution rules” (Fuchs et al., 2004, p. 422). Students in these studies were prompted to search novel problems for familiar problem types (shopping list problems, bag problems, half problems, and pictograph problems) or sort problems into the learned problem types prior to applying learned solution procedures. However, their focus on superficial problem features (e.g., different format, different key vocabulary, additional or different question, irrelevant information) rather than the underlying mathematical structure (e.g., compare) is not consistent with schema construction theory. In addition, story problems in their study were limited to problem types that varied in terms of cover stories and quantities.

Our work builds upon the above-mentioned studies by emphasizing the role of problem schema identification and representation instruction as well as problem solution instruction using
schematic diagrams and teacher-directed instruction to solve a range of problems presented in mathematics textbooks. To date, we have conducted five studies that investigated the effects of SBI for solving arithmetic word problems involving addition and subtraction by students with and without disabilities. Moderate to large effects were found for SBI on immediate (ES = 0.57) and delayed posttests (ES = 0.81) as well as on a generalization test (ES = 0.74) (Jitendra, Griffin, McGoey, Gardill, Bhat, & Riley, 1998). More recently, we conducted a randomized controlled study in inclusive third grade classrooms, with students and teachers randomly assigned to SBI and control conditions (Jitendra, Griffin, Haria, Leh, Adams, & Kaduvettoor, 2005). Results indicated significant and moderate effects of .52, .69, and .65 for the SBI group when compared to the control group on the posttest, delayed posttest (6 weeks later), and statewide mathematics test (a generalization measure), respectively.

In addition, we designed and tested lessons to successfully teach *vary* and *multiplicative compare* problems to students with disabilities (Jitendra, DiPipi, & Perron-Jones, 2001; Xin, Jitendra, & Deatline-Buchman, in press). The study by Xin, Jitendra, and Deatline-Buchman used a pretest-posttest comparison group design with random assignment of subjects to conditions to examine the effects of the SBI and general strategy instruction (GSI) on the word problem solving performance of middle school students with learning problems. Results indicated that the SBI group significantly outperformed the GSI group on immediate (ES = 1.69) and delayed posttests (ES > 2.50) as well as on the transfer test (ES = 0.89).

**Fostering Metacognitive Skills**

In addition to explicit instruction for solving mathematical problems that focuses on the underlying mathematical structure of problems (based on schema theory), it is critical that problem solving instruction addresses metacognition to promote productive and transferable knowledge (De Corte, Verschaffel, & Masui, 2004; De Corte, Verschaffel, & Op’t Eynde, 2000; Shunk & Zimmerman, 1994; Zimmerman, 1989). Many students, especially students with learning problems, fail to spontaneously transfer learned strategies to tasks or situations different from those in the training setting (Chan, 1991; Chan, Cole, & Morris, 1990; Day & Zajakowski, 1991; De Bock, Verschaffel, & Janssens, 1998, Schoenfeld, 1992). Transfer can occur only when the learner recognizes that “the solution principle or strategy in the learned task corresponds to that required in the new task” (Mayer, 1999, p. 15). Therefore, teaching for transfer may involve use of both heuristics and metacognitive strategies, providing instructional support (e.g., corrective feedback, several examples), embedding learning in authentic contexts, and guiding cognitive processing (Mayer, 1999).

Metacognitive skills (e.g., prediction, planning, monitoring, and evaluation) and strategies (e.g., self-questioning, self-monitoring, self-regulation, self-evaluation) that require students to discuss, think aloud, and generally become more aware of the various processes they use to solve problems are known to enhance problem solving (Desoete et al., 2003; Lester, 1983; Montague, 1997). The transition from teacher control to student self-regulation of strategy use is especially important for students at risk for mathematics difficulties who tend to be passive learners (Billingsley & Wildman, 1990; Butler, 1997; Graham & Wong, 1993; McDougall, 1998; Palincsar, 1986; Paris & Newman, 1990). Self-regulated strategy instruction that involves teaching students to monitor their own processes of knowledge and skill acquisition may serve to bridge the gap between effective teacher-mediated instruction and student-managed independent learning (Fuchs, Fuchs, Prentice, Burch, Hamlett, Owen, & Schroeter, 2003; Zimmerman, 1989). Recent research suggests that teaching students to self-regulate their learning has an added
positive effect on their mathematical problem solving performance (Fuchs et al., 2003; Kramarski, Mevarech, & Arami, 2002; Verschaffel, De Corte, Lasure, Van Vaerenbergh, Bogaerts, & Ratinckx, 1999).

Despite the increasing evidence concerning the importance of monitoring understanding during problem solving, schools and classroom instruction do little to effectively promote the development of metacognition in children (Montague, 1992; Montague, Applegate, & Marquard, 1993; Silver & Marshall, 1990). Therefore, an integral part of our instructional approach is problem solving schema-based strategy instruction combined with metacognitive strategy instruction. That is, our instructional approach not only teaches students how to solve a problem, but also regulates their knowledge about solving a problem using self-monitoring procedures (as described in more detail below).

**Proposed Mathematical Problem Solving Instructional Program**

In this project, we will build on our prior work on schema-based instruction (SBI) to design and evaluate an intervention that will promote improved problem solving for all students. The theoretical framework for SBI draws on Cognitively Guided Instruction (CGI), particularly with regard to the categorization of multiplicative problems as the basis for instruction (Carpenter, Fennema, Franke, Levi, Empson, 1999). Similar to CGI, instruction would focus on understanding students’ mathematical thinking in proportional reasoning situations typical of middle school (Weinberg, 2002). However, instruction will be expanded to include teacher-led discussions using schematic diagrams to develop students’ multiplicative reasoning (Kent, Arnosky, & McMonagle, 2002). Specifically, teacher-led discussions will show students how to symbolically represent problems using schematic diagrams, because many students fail to see or recognize the categorizations of multiplicative problems and understand that situations appearing as new can be constricted to the gist of categorizations offered by the schematic approach (Nesher, Hershkovitz, & Novotna, 2003).

Our instructional model has the following components. First, instruction is organized into three-day units to target specific problem types (e.g., vary and multiplicative compare). Focusing instructional blocks on particular problem types, rather than mixing multiple types within the same unit, allows for a greater emphasis on the underlying structure of problems.

Second, instruction will make use of schematic diagrams as a representation to further highlight students’ awareness of the underlying problem structure. A schematic diagram is a representation of the spatial relationships between parts of an object and spatial transformations (Hegarty & Kozhevnikov, 1999; Janvier, 1987; Sweller et al., 1990; Willis & Fuson, 1988). It is important to note that a schematic diagram is not merely a pictorial representation of the problem storyline but rather shows critical elements of the problem structure. For example, the schematic diagram for a multiplicative compare problem illustrates the relationship (e.g., “Howard read 1/2 as many books as Tony”) between the compared (Howard read 5 books) and referent sets (How many books did Tony read?) to indicate that the compared is a part of the referent. Teachers will provide students with guidance in constructing and interpreting schematic diagrams to aid problem solving.

Third, our problem-solving model will involve two types of processes: problem representation and problem solution (Harel, Behr, Post, & Lesh, 1992; Marshall, 1990; Mayer, 1992; Riley et al., 1983). The first or **comprehension phase** (problem schemata) involves translating the "definitive characteristics, features, and facts" (Marshall, 1990, p. 158) in the problem to construct a coherent representation of the problem. As such, instruction will make use
of linguistic knowledge (e.g., gallons is the plural of gallon) and factual knowledge (e.g., there are 100 cents in a dollar) to determine the meaning of statements in the problems and teach students to integrate the information in the problem into a coherent representation using schematic diagrams. The second phase of problem solving, the solution phase, requires devising a plan (i.e., action schemata) to solve the problem and executing the plan (e.g., strategic knowledge). This phase may involve (a) determining the sequence of steps, (b) selecting the operation (e.g., multiplication, division), (c) setting up the equation, and (d) executing the solution procedures (e.g., multiplying, dividing).

Fourth, teachers will encourage the use of student “think-alouds” to foster the development of metacognitive skills. Teachers will model how and when to use each problem solving strategy (Roehler & Cantlon, 1997) and work with students to reflect on the problem before solving it. For example, students will read the problem aloud and try to understand what problem type it entails. When a new problem type is introduced, teacher questions will prompt students to focus on both similarities and differences between the new problem and previously learned problem. In addition, students will be prompted to describe what strategy can be used for solving the given problem and why it is appropriate as well as how to organize the information to solve the problem. Finally, students will reflect on their understanding of the solution process by asking questions (e.g., “Does it make sense? How can I verify the solution?”).

Fifth, a persistent challenge for teachers is including all students in classroom discussions related to mathematical thinking (Baxter et al., 2002). Research indicates that low-achieving students tend to remain passive in whole class discussions (Chard, 1999). To address this issue, our instructional approach will include solving problems in small peer groups. We will model initial interactions to engage academically low achieving learners in discourse that addresses mathematical thinking. In addition, to sustain the interest of high-ability students and extend their learning, we will include problems revolving around a single context or theme at the end of each unit, in which data may be found in a graph or chart or perhaps a short news item or story and encourage alternate means of reaching solutions.

In Appendix B, we provide an overview of the curriculum and present sample materials from the teacher’s guide to illustrate the critical contribution of schematic representations to our instructional approach in solving multiplicative compare and vary problems.

Practical importance of the proposed intervention. The expected outcomes of the project include: (1) An empirically validated mathematics instructional approach for teaching mathematical problem solving to Grade 6 students, (2) Program materials jointly developed with expert Grade 6 teachers to enhance the existing curriculum materials with respect to problem solving skills, (3) Instructional methods that accommodate the needs of students at risk for math difficulties, and (4) Validated measures of problem solving. Adoption of the intervention can lead not only to improved academic outcomes (test scores), but can improve student attitudes about and interest in mathematics based on prior evidence from small scale field trials of SBI.

Overview of Research

Year I is focused on the development and refinement of the SBI curriculum. In our previous research, we have developed lessons for teaching multiplicative compare and vary problem solving for students with learning disabilities in special education classrooms. The proposed curriculum to teach ratio and proportion is much more extensive, and the design experiment will allow us to develop and test its effectiveness in general education classrooms by working collaboratively with skilled teachers.
Years 2 and 3 will employ rigorous evidence-based standards of scientific research to evaluate the impact of the instructional intervention. We will randomly assign teachers to intervention or control conditions. Instructional measures that are psychometrically sound will be used to investigate the effects of the intervention on students’ mathematics achievement, especially problem solving performance. Outcomes from the first experimental study in Year 2 will inform us about the overall effects of SBI and SBI-SM as well as differential student effects on mathematical problem solving. In addition, in Year 3 we will examine the impact of the instructional intensity of the SBI-SM (tutoring added for low achievers) to improve the learning outcomes for those students who are most at-risk for math difficulties. Figure 1 below provides an overview of the project.

<table>
<thead>
<tr>
<th>Year 1 (06-07)</th>
<th>Year 2 (07-08)</th>
<th>Year 3 (08-09)</th>
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<tr>
<td><strong>Design Experiment</strong></td>
<td><strong>Formal Experiment I</strong></td>
<td><strong>Formal Experiment II</strong></td>
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<tr>
<td>Study 1</td>
<td>Study 2</td>
<td>Study 3</td>
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<td>• Intervention Development &amp; Refinement</td>
<td>• Intervention Efficacy</td>
<td>• Intervention Efficacy</td>
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<tr>
<td>• Measurement Refinement &amp; Validation</td>
<td>• Implementation and Analysis</td>
<td>• Implementation and Analysis</td>
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<tr>
<td>SBI (50 students); SBI-SM (50 students); Control (50 students)</td>
<td>SBI (225 students); SBI-SM (225 students); Control (225 students)</td>
<td>SBI-SM (225 students); SBI-SM + tutoring (225 students); Control (225 students)</td>
</tr>
<tr>
<td>Sample: From four Grade 6 Classrooms: 150 students (Cohort I) and 6 teachers</td>
<td>Sample: From 27 Grade 6 Classrooms: 675 students (Cohort II) and 27 teachers</td>
<td>Sample: From 27 Grade 6 Classrooms: 675 students (Cohort III) and 27 teachers</td>
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The following section presents the rationale and overview of study design, research questions, participants, measures, and data analysis procedures for each year of the study.

**Study 1: Curriculum Development and Materials Piloting**

Study 1 in the first year of the project is focused on materials development, initial piloting, and teacher implementation issues using a design experiment (Gersten, Baker & Lloyd, 2000). We will initiate a cycle of material development, field testing materials in classrooms by working with a range of learners (e.g., students with learning disabilities, English language learners) in four Grade 6 classrooms in both whole class and small group formats. In addition, we will work closely with the teachers to support them in their use of the problem solving intervention as they engage all learners in mathematical discourse. Scripted instructional procedures for both SBI and SBI-SM conditions will focus on mediating instruction and initiating discussions and group activities to facilitate mathematical reasoning and thinking skills. In addition to the problem solving procedures, teachers in the SBI-SM condition will teach students to activate metacognitive processes using the self-monitoring checklists. A pretest-posttest-retention test design will be employed to determine the utility and feasibility of the intervention for a wide range of students in the four Grade 6 classrooms, with each of the two interventions, SBI and SBI-SM, implemented in two classrooms. In addition, students from two Grade 6 classrooms will serve as a control group and complete the posttests only.

During the design experiment, we will use ongoing teacher and student measures (e.g., informal interviews with teachers, video recordings of weekly problem solving, audio tapes of small group interactions involving selected target students, field notes of classroom interactions) to assess and refine the intervention as well as support teachers in their implementation. For example, student think aloud procedures during individual assessment of problem solving can help us understand how students monitor their problem solving skills and understand the nature and intensity of instruction necessary to promote application of learned skills to solve problems.
Field-notes of classroom interactions during the lessons can focus on teacher implementation (e.g., introducing procedures, leading discussions) and student participation and responsiveness to instruction (e.g., answers questions, raises hand, correctly maps information on schematic diagrams) as well as interactions (e.g., identifies problem, represents the problem with a diagram or number model, answers and asks questions, uses relevant terms to discuss how problem was solved) with other students. The observations will provide information about opportunities students have to explain, reason, represent, and solve problems and how they respond to the opportunities. Data from teacher interviews and classroom observations can inform us about contextual variables related to the intervention (e.g., examples presented, opportunities to respond, prompts, practice, feedback provided) or teacher implementation (e.g., interactions in small groups, monitoring students with learning problems) that moderate student learning. In short, the field-testing of the curriculum and measures would allow us to identify concerns with intervention implementation, the types of adaptations that students with math difficulties need as well as determine whether the measures can be used to reliably assess student learning.

**Study 1: Research Questions**

The key objectives of Study 1 include: (a) developing, field testing, and refining the schema-based instructional approach and (b) developing and validating measures to evaluate student problem solving skills.

1. What combination of instructional materials, tasks, and application activities most effectively help students develop competent problem solving skills and build metacognitive skills? How can the problem-solving intervention be effectively and efficiently implemented for 30-40 minutes a day by teachers under typical classroom conditions?

2. What group and individually administered student performance measures can be used to assess students’ problem solving skills?

3. How does the mathematics problem-solving intervention (SBI and SBI-SM) impact student engagement and participation? Do high, average, and low achievers respond differently to the intervention?

4. What is the effect of the mathematics problem-solving intervention (SBI or SBI-SM) on student acquisition, retention, and transfer (near and far) of problem solving skills compared to a comparison group of students receiving conventional mathematics instruction? Do high, average, and low achievers respond differently to the intervention?

5. How do teacher perceptions about implementing the problem-solving intervention (SBI or SBI-SM) change over time?

**Study 1: Sample Participants**

A convenience sample of teacher and student participants for the study will be selected from a middle school in Easton Area School District (EASD) that includes 27 sixth grade classrooms. EASD is a diverse district of 8,364 students, with 31% minority enrollments and 25% of the students qualifying for free or reduced lunch. The district includes two middle schools: one serves Grades 5 and 6 and the other serves Grades 7, 8, and 9. See Table 1 in Appendix A (p. 4) for information about the district and the middle school participating in the study.

Teacher participants. Because the major focus in Year 1 is the problem solving program development, four Grade 6 general education teachers will be recruited as participants based on their expertise in mathematics curriculum and instruction. We recently worked with EASD and conducted a study with random assignment of students and teachers to experimental and comparison conditions. For the proposed project, we will again work with this school district to recruit four Grade 6 teachers to serve on the intervention development team and to pilot the
curriculum materials. Teachers will work with the intervention team to field test the problem solving intervention using the SBI or the SBI-SM strategy instruction. In addition, we will recruit two teachers and their students to serve as control groups for the posttest assessment.

Student participants. All students in the four teachers’ classrooms will participate in Study 1. Teachers will test the intervention materials and strategy with their students. Project staff will collect implementation data and administer assessments to students in these classrooms to determine the efficacy of the intervention lessons. The ultimate goal of the assessments is the development of measures of problem solving that will be administered to students during the two formal experiments in Years 2 and 3 to determine the degree to which students in the intervention group are learning problem-solving skills compared to students in the comparison group. At the same time, we will use pretest and posttest data to examine the impact of the problem-solving curriculum for levels of initial student ability status in the classrooms. Pretest data on the word problem solving measure will be used to stratify students in each classroom into three groups: (a) low performing students or students at risk for mathematics learning difficulties (LO; below the 25th percentile); (b) average performing students (AV; between the 25th and 75th percentile), and (b) high performing students (HI; above the 75th percentile). In addition, all students in the comparison groups receiving conventional mathematics instruction will participate by completing the posttest measures only.

While a broad range of Grade 6 students will be represented in the pilot assessments, we will also target 6 students (i.e., 2 high, 2 average, and 2 low achievers) in each classroom so that we can observe and study in-depth the variables (e.g., interactions with teachers, peers, instructional modifications) mediating student understanding and learning. These 6 students per classroom will also be assessed individually on problem solving measures at pretest and posttest. The individual sessions will be tape recorded and transcribed for later scoring.

Study 1: Professional Development

Teachers assigned to the SBI condition will attend a one day training session that will describe the goals of the study and how to mediate instruction and facilitate discussions and group activities. Project PIs Jitendra and Star, who have experience with teacher training, will conduct the training. In addition, on-going professional development will be provided every two weeks during the implementation. The professional development materials will include: (a) videotapes of teachers from previous research implementing SBI to demonstrate essential features of SBI (e.g., problem identification, representing the problem, planning for the solution) and how to introduce these procedures and elicit student discussions, such as how to know if the problem is a multiplicative compare or vary situation, (b) explicit lesson plans that include problem solving tasks to permit teachers to learn how to represent problems using schematic diagrams, explain common rules and procedures, and analyze students’ solutions and explanations, and (c) self-monitoring checklists (for the SBI-SM condition) and how to embed and use metacognitive questions in the unit. Further, project team members will meet with each teacher individually before and during the implementation to address individual concerns. Teachers in the control condition will attend a half-day training session describing the goals of the study, the problem solving content, and how to improve student performance on the state assessment. In addition, professional development will be focused on implementing the standard curriculum faithfully.

Study 1: Measurement Development

A primary goal of Year 1 will be the development of alternate forms of word problem solving measures and a teacher intervention implementation fidelity observation protocol that
will be used during all three years of the project. The measurements and administration schedule is presented in Table 2 and described in more depth below.

Table 2. Measurement Administration Schedule for Study 1

<table>
<thead>
<tr>
<th>Measures</th>
<th>Pre Intervention</th>
<th>Post Intervention</th>
<th>One month following end of intervention</th>
<th>End of School Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SBI n=2</td>
<td>SBI-SM n=2</td>
<td>Control n=2</td>
<td></td>
</tr>
<tr>
<td>SAT-10</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>WPS 1</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>WPS 2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SoC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Treatment fidelity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. SAT = Stanford Achievement Test-Tenth Edition; SoC = Stages of Concern Questionnaire; WPS 1 = Word Problem Solving tests of acquisition and retention; WPS 2 = Word Problem Solving tests of transfer; n = number of classrooms; SBI = Schema-based instruction; SBI-SM = Schema-based instruction + self-monitoring.

Word problem solving (WPS) measure: Tests of acquisition and retention. We have developed a set of alternate forms of problem solving measures that were used in previous research (Xin, Jitendra & Deatline-Buchman, in press) to assess the effects of SBI on the acquisition and retention of mathematical problem solving performance of middle school students with learning problems. The WPS measures required students to respond to 16 one-step multiplication and division word problems (multiplicative compare and vary). Items on the WPS measure included each of several variations of multiplicative compare and vary problems that were similar but not identical to those used during the intervention. Multiplicative compare problems included items in which the unknown quantity involved the compared, referent, or the scalar function. Vary problems included items in which one of the four quantities was unknown. The alternate forms of the tests differed only with regard to the story context and numerical values in the problem. The mean parallel form reliability of the tests was 0.84 (range = .79 to .93). While these measures are reliable and sensitive to changes in students’ problem solving performance, they may not address the entire content of the proposed program. Therefore, our goal in Year 1 is the development of three alternative forms of these measures (pretest, posttest, and delayed posttest) to be administered as a formative measure of problem solving that is aligned with the proposed program objectives.

Also, we will develop assessments of problem solving that are brief (2 to 4 items) and closely aligned to the problem-solving application activities in the intervention. These assessments will be individually administered to 6 target students in each classroom at pretest and posttest. An interview format that requires students to think aloud as they solve the problems will be used to determine their strategy use and thinking. The purpose of these assessments is to yield information that will help us further refine the intervention to meet the needs of all students.

Word problem solving (WPS) measure: Tests of transfer. During Study 1, we will also develop two alternate forms of measures that require students to apply skills to novel problems not targeted during the intervention. Each of these measures will assess near and far transfer skills. To assess near transfer, we will design the measure to include irrelevant information and combine problem types (multiplicative compare and vary) that require more than one-step
solutions. A far transfer measure will be designed to include a multiparagraph narrative with "real life" features (data in a graph or chart), combine problem types that require all four operations, and contain irrelevant information similar to the assessment system used by Fuchs et al. (2004). This problem solving performance assessment will evaluate a number of process variables (e.g., reasoning, communicating) that will be a part of the assessment.

During Study 1, we will validate the utility of the WPS measures as indicators of student learning. Specifically, we will estimate internal consistency reliability of the measures and calculate concurrent validity coefficients with a criterion measure (e.g., SAT-10 mathematics subtests). In sum, we will develop, field test, and validate all WPS assessments to be administered during the study.

Mathematics Problem Solving and Procedures Subtests of the Stanford Achievement Test-Tenth Edition [SAT-10] (Harcourt Brace & Company, 2003). The Stanford 10 is a norm-referenced, group administered achievement test with adequate reliability (coefficient alpha is above .80) and validity. It includes two mathematics subtests that assess mathematical content recommended by the National Council of Teachers of mathematics (NCTM, 2000). The content of the Problem Solving subtest is designed to assess number theory, geometry, algebra, statistics, and probability. The Procedures subtest assesses computational skills that are presented in context. The two mathematics subtests will be used to assess sixth graders general mathematical knowledge and skills (far transfer).

Treatment implementation fidelity. Essential components of the intervention will be identified and included on the fidelity observation instrument to focus on the delivery of critical information. The purpose of the treatment fidelity measure is to ensure that the intervention is being implemented as intended. During Study 1, we will videotape a sample of four representative lessons in each classroom and analyze them to obtain an implementation profile for each teacher.

Stages of Concern Questionnaire (Hall & Loucks, 1978). This 35-item measure is designed to identify concerns teachers experience during implementation of a teaching innovation. On a Likert scale, teachers indicate their concerns about aspects of an innovation or approach. Research has shown that teachers’ concerns about using new interventions change over time from concerns about managing the logistics and materials of the intervention to concerns about being able to document the impact of the intervention on student learning outcomes (Hall & Hord, 2001). Technical adequacy data indicate test-retest reliability correlates ranging from .65 to .86 and internal consistency estimates ranged from .64 to .83.

Study 1: Data Analysis
Data from Study 1 will permit both quantitative and qualitative analyses. We will contrast the change in performance of students experiencing math difficulties with those not experiencing math difficulties in each of the intervention conditions. We will conduct a two-way analysis of variance (ANOVA; 2 intervention groups x 3 initial ability status groups) on each problem solving measure. Our analytic procedures will be applied to improvement scores, as a means of investigating treatment efficacy. We will also conduct an analysis of covariance with the pretest as the covariate on each problem solving measure to check the consistency of results obtained from each ANOVA using change scores. Both procedures are known to be equally acceptable for analyzing two-wave data, with each involving a different set of issues. This data will be used to modify the intervention to ensure increasingly higher levels of student learning. To examine retention of problem-solving skills of students in the intervention conditions, we will also conduct a repeated measures ANOVA on the problem-solving measure (2 intervention groups
SBI and SBI-SM x 3 initial ability levels [low, average, and high] x 3 time [pre, post, and 1-month follow up]). Finally, to validate the efficacy of the treatment, we will compare posttest scores for the intervention groups to a comparison control group using two-way ANOVA (3 ability level x 3 intervention group [SBI, SBI-SM, control]). In all analyses, the nested structure of students within classrooms will be included in the analysis. In addition, we will examine students’ WPS test responses for each problem on pretest and posttest evidence of application of the problem-solving strategy. We will also use the data collected during classroom observations and teacher interviews to inform our ongoing refinements of the intervention. Further, teacher responses to the Stages of Concern questionnaire, observations of mathematics instruction, and student measures of performance will provide direct and indirect measures of teacher change. Consequently, we will use qualitative data analysis methods (Miles & Huberman, 1994) to understand intervention impact on student learning as well as teacher change. This data will be used to inform modifications of the intervention to ensure increasingly higher levels of student learning. We will work with project consultant Woodward in interpreting the qualitative data from the design experiment.

**Study 2**

We will conduct formal experiments in Year 2 (Study 2) and 3 (Study 3) to determine the impact of the problem-solving curriculum. The formal experiments will not only focus on the overall impact of the intervention, but also systematically investigate its effect on students at-risk for mathematics difficulties. Another goal of these studies is to examine student attitudes about mathematics.

The overview of the study design for Study 2 is as follows. We will randomly assign all 27 Grade 6 classrooms/teachers to three groups: (a) control, (b) SBI, and (c) SBI-SM. Students will be pretested on four measures (SAT-10, WPS measure of problem solving, and the two WPS measures of transfer described in Year 1). Scores on the WPS measure of problem solving will be used to designate children as low, average, or high performing. In addition to randomly assigning teachers to condition, we will also match experimental and comparison classrooms on pretest data, and key demographic and student variables (e.g., SES, ELLs). We do not anticipate any systematic differences between students in experimental and comparison classrooms, but if any significant differences are found, appropriate covariant data analysis procedures to account for pretest differences on student learning outcomes. Teachers in the experimental condition will implement the SBI problem-solving program and teachers in the comparison condition will implement problem-solving instruction on the same topics (e.g., multiplication) using the district adopted grade 6 textbook, *Mathematics* by Scott Foresman (Charles, 2004). All instruction will occur during the regularly scheduled mathematics instructional period. Because SBI is a highly specified program with designated teacher-student discourse, materials, and activities, we do not anticipate carryover from the SBI condition to typical classroom practice condition. We will monitor the implementation fidelity of both curricula and further stress the importance of implementing the standard curriculum faithfully during teacher training to ensure that contamination effects between intervention and comparison groups do not occur. In both conditions, mathematics instruction will occur for approximately 30-40 minutes per day, 3 days a week for 12 weeks. The amount of math instruction will be held constant across conditions. Finally, students will be posttested on all measures to determine the overall impact of the intervention. In addition, the WPS measure of problem solving will be given approximately one month after the termination of the intervention to determine the long-term retention effects of the problem solving intervention.
This controlled within-school design has a number of advantages over alternate designs. It eliminates major threats to the validity of the study, such as school effects and student selection effects that would otherwise compromise the precision of the treatment effects. Although teacher effects (differences in instructional effectiveness) are an issue with the design, the random assignment of teachers to conditions should minimize this threat. At the same time, we will examine factors such as level of education and years of teaching experience to rule out differences between conditions prior to the beginning of the study. A concern about the possibility of student and teacher attrition is less of an issue based on the low dropout rates in this district. Also, we are not tracking student scores over multiple years. Nevertheless, we will account for student mobility in the statistical analysis of data. To address teacher attrition, we budgeted for additional teacher training for the third year of data collection so that we can replace any teachers who leave the school or the study. On the other hand, results from this study are limited to sixth grade students in this one school. This threat to external validity necessitates that future research (e.g., a multi-site evaluation of the intervention) is conducted to generalize the study findings.

Study 2: Research Questions

1. What are the differential effects of SBI, SBI-SM, and conventional mathematics instruction on measures designed to assess directly students’ acquisition and retention of problem solving skills? Is there a differential impact for high, average, and low achievers?

2. What are the differential effects of SBI, SBI-SM, and conventional mathematics instruction on measures designed to assess near and far transfer of students’ problem solving skills? Is there a differential impact for high, average, and low achievers?

3. What are the differential effects of SBI, SBI-SM, and conventional mathematics instruction on students’ beliefs and attitudes about problem solving skills? Is there a differential impact for high, average, and low achievers?

4. Is there significant variation in students’ self-monitoring performance as a function of treatment condition? Is the effect moderated by student initial achievement status (high, average, low achievers)?

5. How do teacher perceptions about implementing the problem-solving intervention (SBI or SBI-SM) change over time?

Study 2: Sample Participants

Teacher participants. We will work with all 27 sixth grade teachers in EASD. Recruitment efforts will focus on the importance of developing middle school students’ mathematical competence, the project’s potential to significantly improve the mathematics problem solving performance of all Grade 6 students, and the teacher training provided to participating teachers. Teachers will also receive a modest stipend each year for their efforts. Participating teachers must agree to three project requirements: (a) random assignment to experimental or comparison group; (b) teacher training targeting implementation prior to the beginning of the school year and as needed during the course of the study based on implementation fidelity data; and (c) allowing project staff to conduct classroom observations and assessments.

At the beginning of Study 2, teachers will be randomly assigned to experimental or comparison groups. Teachers assigned to the control group will implement their standard curriculum for two years, with a new cohort of Grade 6 students each year. While teachers assigned to the SBI-SM intervention group will continue to implement the same intervention in Year 3, teachers assigned to the SBI intervention group will be assigned to the SBI-SM plus tutoring group in Year 3. Teachers in both intervention groups will work with a new cohort of
Grade 6 students each year. After two years, if the problem solving intervention process is effective, we will provide professional development to teachers in the comparison group at no charge. This is intended to serve as an incentive for teachers assigned at the outset of the study to the comparison group that they will eventually receive the training in the intervention.

**Student participants.** All students in the 27 classrooms will participate in Study 2. Students in experimental and comparison classrooms will be administered all measures at pretest and posttest. Pretest data on the WPS measure will be used to stratify students in each classroom into three groups (LO, AV, HI) as in Year 2

**Study 2: Professional Development**

Professional development techniques will be the same as Study 1.

**Study 2: Measures**

All students in the experimental and control classrooms will complete the range of performance measures described above to assess the intervention impact. The administration schedule is presented below in Table 3.

Table 3. Measurement Administration Schedule for Studies 2 and 3.

<table>
<thead>
<tr>
<th>Measures</th>
<th>Pre Intervention</th>
<th>Post Intervention</th>
<th>One month follow-up</th>
<th>End of School Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SBI n=9</td>
<td>SBI-SM n=9</td>
<td>Control n=9</td>
<td>SBI n=9</td>
</tr>
<tr>
<td>SAT-10</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>WPS 1</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>WPS 2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SM quest.</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>SoC</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>TOMA</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Treat. fidelity</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Once every two weeks for the duration of the intervention

Note. SAT = Stanford Achievement Test-Tenth Edition; SM quest. = self-monitoring questionnaire; SoC – Stages of Concern Questionnaire; WPS 1 = Word Problem Solving tests of acquisition and retention; WPS 2 = Word Problem Solving tests of transfer; TOMA = Test of Mathematical Ability Attitude subtest; n = number of classrooms; SBI = Schema-based instruction; SBI-SM = Schema-based instruction + self-monitoring; \*SBI will be replaced by SBI-SM + ad hoc tutoring in Year 3.


**Word problem solving (WPS) measure: Tests of acquisition, retention, and transfer.** The development of these measures was described in Study 1 above. All students in the intervention and control classrooms will be administered the measure of WPS (see Table 3).

**Self-Regulation Questionnaire** (Fuchs et al., 2003) assesses students’ self-regulation processes using several statements that focus on self-efficacy, goal-orientation and self-monitoring, and effort. Responses are coded as true (1 point), kind of true (2 points) and not true (3 points). The authors report strong interrater agreement of 100% in their research.

**Treatment fidelity.** The development of the fidelity measure was described under Study 1. Measures of fidelity will occur once in two weeks for each teacher and will be collected for the entire 30-minute mathematics lesson. Sessions will be videotaped for scoring fidelity of treatment implementation. The fidelity implementation checks serve two purposes. The first is to ensure that intervention teachers are implementing the intervention as intended. If fidelity is low,
or if teachers have questions about implementation, the bi-weekly fidelity checks will give project staff the opportunity to provide clarification or more training, to make sure that implementation objectives are met. The second purpose of the fidelity checks is to document differences between instruction in intervention and comparison classrooms.

*Stages of Concern Questionnaire* (Hall & Loucks, 1978). This was described in Study 1 above.

*Attitude toward mathematical problem solving.* The Attitude Toward Math subtest of the *Test of Mathematical Abilities-2* (TOMA-2) (Brown, Cronin, & McEntire, 1994) will be used to measure students’ beliefs and attitudes toward math. This test consists of 15 items that students respond to by choosing the statement that best reflects their feeling: “yes, definitely,” “closer to yes,” “closer to no,” and “no, definitely.” Example items include “It’s fun to work math problems,” “I like everything else in school better than math,” and “Math is interesting and exciting,” and “I use math a lot outside of school.” The test provides evidence of adequate reliability (coefficient alpha = .86 for Grade 6) and validity. The total score from this measure, which is the sum of responses to the 15 items, will be used for analysis.

*Study 2: Data Analysis*

Because teachers will be assigned randomly to conditions, we will use teacher as the unit of analysis, with students of differing initial status (Low, Average, High) nested within teacher. This will allow us to compare effects among students of varying status in the same classrooms and to test interactions between initial status and condition. Consequently, we will conduct a two-factor mixed model analysis of variance (ANOVA) on each problem solving measure to focus on differences between students in the intervention and comparison groups on identifying students for whom the intervention is most successful. Our analytic procedures will be applied to (a) pretreatment scores, as a means of examining treatment group comparability and (b) improvement scores, as a means of investigating treatment efficacy. We will also conduct an analysis of covariance with the pretest as the covariate on each problem solving measure to check the consistency of results obtained from the ANOVA using change scores. Both procedures are known to be equally acceptable for analyzing two-wave data, with each involving a different set of analytical issues. To evaluate pairwise comparisons for significant effects, we will use the Fisher least significant difference (LSD) post hoc procedure (Seaman, Levin, & Serline, 1991). To examine retention of problem-solving skills over the three measurements, a growth model approach will be utilized with the mixed model ANOVA, including the same factors proposed for the pretest/posttest data (i.e., intervention group, ability level, and student nested within teacher). To investigate the effects of self-regulation as a function of treatment, a two factor mixed model ANOVA will be applied to posttreatment self-regulation scores. To estimate practical significance of effects, we will compute ESs by subtracting the difference between improvement means and then dividing by the pooled standard deviation of improvement/square root of 2(1 –r_{xy}) (Glass, McGraw, & Smith, 1981). In addition, we will examine the comparability of the three groups in terms of teachers’ age, gender, degree, and years of teaching experience as well as students across the two conditions in regard to subsidized lunch status, sex, race, special education status, and English as a second language status using chi-square tests for nominal data and t-tests or ANOVA for interval data. We will use appropriate covariant data analysis procedures if significant differences are found among conditions on these variables. As in Year 1, teacher responses to the *Stages of Concern* questionnaire, observations of mathematics instruction, and student measures of performance will be examined to provide direct and indirect measures of teacher change.
**Power calculations.** Study 2 is expected to have a large sample size (27 classrooms with about 25 students per classroom = 675 students). With moderate treatment effects expected, the power to detect significant differences is at or near the maximum (.99 or above), even when 50% attrition is calculated, allowing even small differences between groups to be detected at alpha level of .05.

**Study 3**

The design of Study 3 will address the instructional needs of the lowest performing students. While we predict that all students (low, average, and high achieving) will do better in intervention (SBI and SBI-SM) than control classrooms and that student outcomes for SBI-SM treatment condition will be better than that for SBI only in Study 2, there will still be a considerable discrepancy between the performance of at-risk and other students within intervention classrooms. Typically, classroom instruction is geared toward average performing students, and students who are struggling are often left behind. Because students at risk for mathematics difficulties respond more slowly than their normally achieving peers with respect to mathematical problem solving, providing more time and productive practice may be crucial to help them benefit from the intervention (Fuchs, Fuchs, & Prentice, 2004). Therefore, the design of Study 3 will address this discrepancy by providing instructionally intensive treatment (extended practice in problem solving using small group ad hoc tutoring) for students at risk. We hypothesize that this intensive treatment will result in a statistically significant decrease in the gap between at-risk and other students within intervention classrooms. Intensive, small group or individualized intensive instruction is a well-substantiated practice for struggling learners (Foorman & Torgesen, 2001). Further, we will ensure that teachers assigned to the SBI condition will implement the intervention for two years to capture any improvements in implementation after a semester of experience with the intervention.

The overview of the study design for Study 3 is as follows. Grade 6 teachers assigned to the control group or SBI-SM in Study 2 will implement their standard curriculum or SBI-SM; whereas teachers assigned to the SBI intervention group in Study 2 will be assigned to the SBI-SM plus tutoring group. All teachers will work with a new cohort of Grade 6 students. As in Study 2, students in all three groups will be pretested on four measures (SAT-10, WPS measure of problem solving, and the two WPS measures of transfer described in Year 1). On the basis of the WPS measure of problem solving, children will be designated as low, average, or high performing. In addition to randomly assigning teachers to condition, we will also match experimental and comparison classrooms on pretest data, and key demographic and student variables (e.g., SES, ELLs). Teachers in the experimental conditions will implement the problem-solving program and teachers in the control condition will implement their standard problem solving mathematics curriculum. In both conditions, mathematics instruction will occur for approximately 30-40 minutes per day, 3 days a week for 12 weeks. In addition, target students (low achievers or students at risk) in the SBI-SM condition will receive tutoring 2 days a week during study skills period. Tutoring of target students would be business as usual without affecting the rest of the class, because the study skills period is used flexibly for one-on-one or small group instruction, or assisting students when they work on homework or other class assignments. The tutoring will focus on helping students understand the problem and how to use the problem solving strategy for solving it. Teachers will explain the problem solving steps using several examples, guide students as they process the problems, provide productive feedback as they practice applying the strategy to solve problems, and encourage students to participate in
learning within groups. Finally, students will be posttested on all four measures to determine the overall impact of the problem-solving curriculum. In addition, the WPS measure of problem solving will be administered approximately one month after the termination of the intervention to determine the long-term retention effects of the problem solving intervention.

**Study 3: Research Questions**

1. What are the differential effects of SBI-SM, SBI-SM with tutoring (for low achievers only), and conventional mathematics instruction on measures designed to assess directly students’ acquisition and retention of problem solving skills? Is there a differential impact in terms of improvement from pretest to posttest for high, average, and low achievers?

2. What are the differential effects of SBI-SM, SBI-SM with tutoring, and conventional mathematics instruction on measures designed to assess near and far transfer of students’ problem solving skills? Is there a differential impact in terms of improvement from pretest to posttest for high, average, and low achievers?

3. What are the differential effects of SBI-SM, SBI-SM with tutoring, and conventional mathematics instruction on students’ beliefs and attitudes about problem solving skills? Is there a differential impact for high, average, and low achievers?

4. Are the differential effects of the intervention on student outcomes moderated by teachers having prior experience with the SBI-SM intervention?

**Study 3: Sample Participants**

*Teacher participants.* All teachers who participated in the formal experiment in Study 2 will participate in Study 3.

*Student participants.* Study 3 student participants will be yoked to the participation of their teacher, and students in experimental classrooms will be matched with students in comparison classrooms. All students will be administered the battery of mathematics assessments to determine the overall impact of the intervention on student problem solving performance.

**Study 3: Measures**

The measurement protocol described in Study 2 will be utilized in Study 3 (see Table 3 on p. 14).

**Study 3: Data Analysis**

Data analysis procedures will be similar to those reported in Study 2, with a few variations necessitated by the Study 3 design. Specifically, the proposed design is not a fully-crossed factorial design in that only low ability students within the SBI-SM condition will receive tutoring. Thus, we will conduct a one-factor mixed model ANOVA using the seven groups (a low ability group receiving both SBI-SM and tutoring plus the 6 groups created by crossing 3 ability levels with 2 treatment conditions [SBI-SM and control]). For the analysis of acquisition and retention, appropriate *a priori* contrasts are proposed as follows: (1) average change for low ability students receiving SBI-SM plus tutoring is significantly greater than other low ability students and (2) the difference between low ability students who received SBI-SM plus tutoring and higher ability students will be reduced relative to low ability students who did not receive tutoring. Any necessary post hoc comparisons will be made using the Fisher least significant difference (LSD) procedure (Seaman et al., 1991). Appropriate covariates will also be included in the analyses. In addition, case studies will be conducted with the nine teachers who will implement the SBI-SM in Studies 2 and 3. Qualitative analyses will focus on multiple sources of data. For example, teacher responses to *Stages of Concern* Questionnaire, observations of mathematics instruction, and student measures of performance will provide direct and indirect measures of teacher change. We will use constant comparative methods to analyze changes in
implementation among teachers and use field notes to explain these observed phenomena (Miles & Huberman, 1994).

**3.0 Qualifications of Key Personnel**

**Asha K. Jitendra, PI (.67 FTE),** is a professor and coordinator of special education and faculty to the Center for Promoting Research to Practice –School, Families, and Communities within the College of Education at Lehigh University. Her research focuses on analysis of school-based materials and tasks (e.g., mathematics, reading) as well as instruction and assessment of mathematics and reading skills for students with learning difficulties. She has managed federal research grants totaling approximately $2.3 million. With OSEP funding, Jitendra developed and tested the effectiveness of SBI on the mathematical problem solving performance of third grade students. As the co-PI of a five-year NIMH research grant, she has examined the effects of two different consultation approaches on the reading and mathematics achievement of children in primary grades. Jitendra’s scholarly contributions include more than 50 publications in peer-reviewed journals. She and her colleagues were recognized by the American Psychological Association with an award for an outstanding article in the *Journal of School Psychology*. She serves on seven editorial boards. In addition, she served as the associate editor of the *Journal of Learning Disabilities* and edited two special issues (i.e., Textbook evaluation and modifications for students with learning problems, *Reading and Writing Quarterly; Mathematics Assessment, Assessment and Effective Intervention*). As the PI for this project, Jitendra will coordinate research activities and serve as overall administrator of project activities, funds, and evaluation; director of curriculum materials design and professional development components of the project; and primary contact with the project consultant.

**Jon Star, Co-PI (.36 FTE during Year 1 and .24 FTE in Years 2 and 3),** is an Assistant Professor in the College of Education at Michigan State University. He is a former middle and high school mathematics teacher. His graduate training is in cognitive and educational psychology, and his research focuses on middle and high school students’ learning of mathematics. With funding from IES, Star (in collaboration with Dr. Bethany Rittle-Johnson) is studying the development of procedural flexibility and conceptual understanding in middle school students' mathematical problem solving. With funding from the NSF, Star (in collaboration with Dr. Natasha Speer) is studying the learning and teaching of college mathematics teaching assistants. Star's work has been published in both psychology and mathematics education journals, including the *Journal for Research in Mathematics Education, Cognition and Instruction, Developmental Psychology, Journal of Cognition and Development,* and *Contemporary Educational Psychology*. His primary roles and responsibilities include the design of curriculum materials and professional development components of the project. In addition, Star will assist in analysis and evaluation of research.

**Grace Caskie, Statistician (.22 FTE),** is an assistant professor in the College of Education at Lehigh University. From 1998 to 2004, she conducted post-doctoral work at Pennsylvania State University, which included conducting analyses of cognitive intervention data from two federally funded grants. Caskie has used structural equation modeling and longitudinal data analyses in her research. Her research interests include cognitive development over the lifespan and evaluation of longitudinal measurement designs and analysis methods, focusing on the influence of missing data and time-efficient designs. She is also involved in research on the accuracy of self-reported health information and its link to cognitive change in older adults.
John Woodward (Consultant), is a professor in the School of Education at the University of Puget Sound in Tacoma, Washington. His research has involved bilingual education, instructional interventions for inner city students, technology-based instruction in math and science, and models of professional development. In addition, he conducted federally funded research in the area of mathematics education for academically low achieving students. As the PI of the REACH Institute, a federally funded five-year project, he conducted research that examined methods for helping students with disabilities succeed in standards-based instruction in grades 4 through 8. Woodward has co-authored four technology-based instructional programs for academically low achieving students. He is currently the co-author of Transitional Mathematics and Fact Fluency and More! that is designed to meet the needs of academically low achieving students in the late elementary and middle grades. Fact Fluency and More! has been used in elementary schools in conjunction with reform-based math programs as a way of helping all students master their facts. Woodward has published over 75 articles in professional journals, and has presented on issues in mathematics education in the US, Canada, Australia, and Japan.

4.0 Adequacy of Resources

Lehigh University (LU) is an independent, nondenominational institution that has four colleges and includes 24 institutes. The College of Education (COE) comprising 31 faculty offers graduate programs only and is a major contributor to the University’s instructional and research programs. The COE at LU is ranked in the top 50 nationally in the U.S. News and World Report rankings, with a ranking of 15 overall in per faculty member externally funded, and 10 in doctoral student selectivity among the top 50 ranked Colleges of Education. LU recently chartered the Center for Promoting Research to Practice (CPRP) funded under four legislative initiatives from the U.S. Congress totaling $0.8 million. The proposed project will be under the auspices of the CPRP, which will offer resources including research assistants, space, technical support, and administrative and budgetary support. Over the past three years, the CPRP has successfully competed for $5.7 million of funded projects. Other projects in the COE funded by USDOE, NIMH, and NICHD have totaled $8.4 million over the last five years. In addition, the University’s Computing Center operates 28 microcomputer classrooms, each equipped with a local area network. The university’s library holdings number over 1,000,000 volumes. Resources of the library are augmented by membership in the Center for Research Libraries, Online Computer Library Center, and interlibrary Delivery Service of PA.

The proposed research will take place in a middle school in Easton, PA and a letter of support and commitment is presented in Appendix A (p. 5). Jitendra has on-going relations with the administrators in EASD that will facilitate the successful execution of this project.

Michigan State University will provide facilities to support Star’s role in all phases of this project. Resources provided by Michigan Sate include all necessary office space, office equipment, phones, copying facilities, basic secretarial supplies, and extensive networking and computer backup systems. The departmental research management staff and computer support staff, and the college technology support staff, would support the smooth completion of this research.
References


Gentner, D., Loewenstein, J., & Thompson, L. (2003). Learning and transfer: A general role for analogical encoding. *Journal of Educational Psychology, 95*(2), 393-408.


Harel, G., Behr, M., Post, T., & Lesh, R. (1992). The blocks task: Comparative analysis of the task with other proportion tasks and qualitative reasoning s
kills of seventh-grade children in solving the task. Cognition and Instruction, 9, 45-96.
problem-solving instruction for middle school students with learning disabilities: An 
emphasis on conceptual and procedural understanding. Journal of Special Education, 36(1), 
23-38.
comparison of single and multiple strategy instruction on third grade students’ mathematical 
(AERA) Annual Convention, Montreal, Canada.
mathematical word problem solving by students at risk or with mild disabilities. Journal of 
students with disabilities and at risk: A research synthesis. Journal of Special Education, 
30, 412-439.
Psychology Review, 15, 267-296.
learning difficulties in mathematics: Findings of a two-year longitudinal study. Journal of 
Educational Psychology v94 n3 p586-97 Sep 2002
multiplicative reasoning. In B. Litwiller and G. Bright (Eds.), Making sense of fractions, 
ratios, and proportions: 2002 Yearbook (pp. 145-152). Reston, VA: National Council of 
Teachers of Mathematics.
Psychological Review, 92, 109-129.
Lemke, M. A., Sen, E. Pahlke, L. Partelow, D., Miller, T., Williams, D. Kastberg, & Jocelyn, L. 
(2004). International outcomes for learning in mathematics literacy and problem solving: 
National Center for Education Statistics.
& M. Landau (Eds.), Acquisition of mathematics concepts and processes. New York: 
Academic Press.
problem solving: A study of two grade seven classes (Final report, NSF project MDR 85- 
50346). Bloomington: Indiana University, Mathematics Education Development Center.
Ma, L. (1999). Knowing and teaching elementary mathematics: Teacher’s understanding of


