MIXED METHODS STUDY OF PROBLEM-SOLVING AND METACOGNITION IN THE ELEMENTARY CLASSROOM

A Record of Study

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF EDUCATION

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August 2019

Major Subject: Curriculum and Instruction

ABSTRACT

The implementation of high-stakes testing has radically altered mathematics instruction in elementary classrooms. A curriculum that is heavily focused on developing successful test takers has fostered a weakness in our students' ability to solve complex problems. The purpose of this record of study was to examine the impact of a problem-solving program at a small elementary campus in North Texas. A mixed methods approach was used to examine the effectiveness of the intervention which integrated metacognitive actions with problem-solving skills. The program was examined within the context of student problem-solving, student use of metacognitive strategies, and teacher perceptions of student success. The findings suggest that the intervention was effective in increasing the problem-solving skills and metacognitive actions of third and fourth grade students on our campus. Recommendations include the implementation of a campus-wide, problem-solving model and increased use of guided instruction in mathematics classes. Recommendations for further study include an examination of the effectiveness of implementation with younger students.

DEDICATION

I dedicate this work to my family. I am eternally blessed.

ACKNOWLEDGMENTS

I would like to thank my committee co-chairs Dr. Mary Margaret Capraro and Dr. Robert M. Capraro, and my committee members, Dr. Lynn M. Burlbaw and Dr. Glenda Musoba. Thank you for your guidance and support throughout this project.

I would also like to thank my friends and colleagues, and the faculty and staff for making my time at Texas A&M a wonderful experience.

Lastly, I would like to thank my family for their unending support and encouragement.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a committee consisting of Professors Mary Margaret Capraro, Ph.D., Co-Chair; Robert M. Capraro, Ph.D., Co-Chair; and Lynn M. Burlbaw, Ph.D. of the Department of Teaching, Learning, and Culture and Professor Glenda Musoba, Ph.D. of the Department of Educational Administration and Human Development. All work for this record of study was completed independently by the student.

Funding Sources

There are no outside funding contributions to acknowledge related to the research and compilation of this document.

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CHAPTER I

INTRODUCTION

Problem-solving in mathematics is a challenge for students nationwide. In today's test-driven classrooms, students routinely engage in problem-solving scenarios that are rote and formulaic. Often, mathematics instruction is geared towards ensuring that all students attain a minimal level of mathematical competence and is presented in situations that are devoid of context and have limited use in real-world applications. Our students have high scores on standardized tests but exhibit great difficulty when presented with tasks and scenarios that involve complex, real-life application of concepts. These weaknesses are most notable in mathematics problem-solving in our third through sixth-grade classrooms, but also occur in many other situations that require critical thinking and analysis.

The Context

National Context. In most schools today, the development of student problem-solving capacity is undertaken on a superficial basis. Rather than engaging with authentic challenges that are rooted in a real-world context, students are tasked with responding to well-structured questions that require little more than the application of predetermined strategies and solutions. Students are taught to mine the given information for strategically embedded clues that point toward the desired solution. Success is determined by ensuring that a student has applied the intended strategy to arrive at a specific answer. This approach does a poor job of preparing students to tackle the complex problems faced in real life.

Real-world problems are often ill-structured and seldom provide students with neat and tidy solutions. These challenges which can be very complex and poorly understood require solvers sift through incomplete, suboptimal, and extraneous information to frame problems while addressing competing influences and multidimensional goals (Simon & Newell, 1971). Those solving real-world problems must continually monitor their progress and adjust their focus in response to new information and understandings. The difficulty levels of real-world problems require a high level of independence and self-regulation on the part of the solver.

Situational Context. Cottonwood Elementary is a small, rural school located in an agricultural community in North Texas. The community, with a population of around 1000, has a homogeneous makeup with a racial distribution of 94.11% White, 0.20% African-American, and 4.20% Hispanic. The elementary campus currently has a student population of 144 students in Pre-K through sixth grade. This year, the average class size is just under 14 students with a student to teacher ratio of 9.1:1.

Students in grades Pre-K through first are taught in self-contained classrooms where all subjects are taught by the homeroom teacher. Students in the second through sixth grades follow an eight-period rotation schedule and transition between either two or three teachers' classrooms throughout the day. Most teachers in the upper elementary grades teach multiple sections of the same subject across several grade levels. There are currently three mathematics teachers that provide instruction for students in the second-sixth grades. The reading and math interventionist provides academic intervention for struggling math students.

For the past three years, Cottonwood Elementary has been recognized by the Texas Education Agency as either a High Progress Reward School or a High Performing Reward School. The school also has ranked at or near the top of the campus comparison group in state accountability reports. Passing rates on the Mathematics STAAR Test consistently range from 90% to 95% with approximately one-third of students meeting the Advanced standard. These rates are significantly higher than those of surrounding districts. Passing rates on the mathematics portion of the test are also higher than on the reading and writing portions of the STAAR test. Thus, most of the intervention focus is targeted at boosting literacy skills.

An analysis of campus goals showed no specific focus on student problem-solving. There is a campus goal of maintaining two or more distinction designations on the annual accountability report. The designation in mathematics is based on the percentage of students who score at the advanced level on the mathematics portion of the STAAR test. So, while no specific goal of boosting problem-solving exists, work on developing student problem-solving skills supports stated campus goals.

All students at the elementary school participate in a 90-minute mathematics block. The math curriculum, entitled *Go Math!*, is workbook-based, and provides an optional online component with instructional videos and an electronic version of the textbook. The curriculum is comprehensive and was marketed as providing all aspects of a successful math program. A noted lack of spiraled review led math teachers to implement various review programs. These programs, which provide daily, spiraled practice with essential concepts, were selected to boost student performance on the STAAR test. As a part of the 90-minute math block, students in the second-fourth grade also have time for regular fact practice with addition, subtraction, multiplication, and division.

The Problem

Relevant History of the Problem. Students at Cottonwood Elementary are very successful on state tests with scores that exceed all other area schools, yet teachers report a noticeable weakness when students face challenges that require a deeper application of their knowledge and skills. Teachers frequently report that several students seem unable to think for themselves or take the initiative in attempting challenging work. Rather, students often avoid difficult tasks or quickly seek help and guidance. With class sizes of around fifteen, teachers can quickly provide remediation and additional instruction when students do not master the material. Thus, students are rarely in situations where they must wrestle with work that is too challenging.

Significance of the problem. This problem has both short-term and long-term significance for students and teachers. In the short-term, this problem is significant because our students' limited proficiency in solving complex problems affects their performance in academic endeavors. Many of our students miss out on the strong connections between content and real-life that develop when engaged in challenging problem-based tasks. Additionally, our students are often working on activities that are at a level that is not deep enough to provide a meaningful base for future learning. The long-term significance of this problem is that many of our students will be unprepared to face more rigorous challenges in middle and high school and ultimately in real-world contextual problems.

Research Questions

This study was developed to answer three questions:

1) What strategies or techniques predominate student practices when solving complex mathematics problems?
2) How are/were metacognitive strategies used by students who engaged in solving complex mathematics problems?
3) How do teachers perceive their students use of metacognitive and problem-solving strategies when solving complex problems?

These research questions were selected because they provide an overarching focus and are highly relevant throughout all stages of the study. Additionally, dozens of questions emerged through ongoing qualitative analysis. These lines of inquiry were analyzed within the context of the research questions and provide a deeper understanding of practice and results.

Personal Context

Researcher's Role and Personal History. I currently work as a fifth-grade mathematics teacher and interventionist at Cottonwood Elementary. In this capacity, I work with fellow teachers to meet the needs of struggling students. I have personal experience with the problem through my work as a mathematics teacher and my current work with math interventions.

As an educator with eighteen years of classroom teaching experience, I have an extensive background in elementary mathematics and gifted education. I have completed graduate work in student problem-solving and self-assessment. I have experience with developing and implementing problem-solving curricula at the campus and district level and have collaborated with educators across multiple districts to create common problem-solving assessments.

Journey to the Problem. When I began working at this school, I was surprised to hear the teachers discuss concerns about their students' problem-solving abilities. I worked previously in a somewhat low-performing school in a large city and was highly impressed with the quality of work my new students were doing. STAAR test scores for the district were extremely high, and the majority of our students scored above the 60^{th} percentile on nationally normed progress monitoring assessments. I assumed that the teachers must have had very high expectations and possibly did not realize how advanced many of their students were.

As we began to cover more complex material, I found that our students struggled with tasks that did not follow the same format as the STAAR test. As I watched students work, it became evident that they were heavily reliant on structural cues to solve problems. Students were taught to identify keywords to know what type of strategy or operation to apply in their problem-solving. They also depended heavily on techniques that would allow them to work backward from each given multiple-choice solution to try to find the correct answer. Often, when large numbers of students struggled with specific tasks, it was because these cue words or structural cues were missing or differed from the type they regularly saw.

In my role as a math interventionist, I worked with teachers to create more authentic, open-ended assessments that require the application of skills that our traditional assessments indicated that the majority of our students had mastered. These assessments lacked the structural cues, keywords, and multiple-choice answers found in the questions teachers usually provide to students. Less than one-quarter of our students passed these open-ended assessments. Students described being frustrated because they thought the problems were confusing and they had no way to know if their strategy was correct.

Interviews with members of the school community highlighted four significant concerns about student problem-solving. First, students have a difficult time relating their tasks in mathematics classes to real-life situations. Second, rather than try to understand all the facets of a problem, students typically rely on structural cues to guide them. Third, many students have a difficult time applying previously mastered concepts in new or progressively demanding situations. Finally, students have a difficult time justifying their answer without referring to the given structural cues or key words.

I initially framed this situation in the context of a lack of problem-solving and critical thinking skills. Our students were successful at following a prescribed set of steps to select the correct multiple-choice answer. What they lacked, was the ability to analyze problems and identify possible approaches based on goals set for each task. Additionally, several students seemed to lack an awareness of how successful they were in solving problems. Rather than being able to identify specific areas where they struggle, many of our students were typically only able to explain that they did not know what to do.

Significant Stakeholders. The classification as a quality improvement project enables us to tailor the design of the study to the unique needs of the school. From its inception, this study was driven by the needs of stakeholders. The initial information gathering process relied heavily on the input of teachers, students, administrators, parents, and community and business leaders. As with any community, the viewpoints and perceptions of stakeholders are interconnected and crucial in forming the design of the study. As the study moved from the design phase to implementation, students and teachers were the stakeholders of significance. Teachers and administrators are the primary audience for the results, discussion, and recommendations.

Important Terms

For the purpose of this project the following definitions will be used:

1. Calibration: Within the context of metacognition, calibration is used to describe the accuracy of a students' perception of tasks, information, feedback, and their performance and ability, and is an essential element of successful self-regulation (Glenberg & Epstein, 1985; Winne, 2004).

2. Cognitive Labs: A cognitive lab is a procedure used to study the thinking and metacognitive processes of an individual as they work through a task. During the cognitive lab, the student engages in a think-aloud process to solve a problem (Ericsson & Simon, 1998) before taking part in a retrospective report when they describe the steps and thoughts they utilized (Dickenson, Price, Bennett, & Gilmore, 2013; Gewertz, 2012).
3. Critical Thinking: For this study, I used the following child-friendly definition that was developed by campus mathematics teachers. "Critical thinking is thinking carefully about, and understanding all parts of a problem, and coming up with a thoughtful answer, solution, or argument."
4. Domain Specificity: Domain specificity refers to the extent to which, rather than being broadly applied, a students' metacognitive skills are often only able to be utilized in a narrow domain-dependent context (Jacobse & Harskamp, 2012)
5. Guided Instruction (GI): Fisher and Frey (2010) describe guided instruction as "saying and doing the just-right thing to get the learner to do cognitive work" (p. vii). In this instructional approach, the teacher uses a wide range of strategies to foster the gradual transfer of responsibility for thinking and learning to students.
6. Metacognition: The process of thinking about one's thinking. In this context of this study, metacognition consists of self-assessment, which includes metacognitive knowledge and experience, and self-regulation, which includes planning, goal setting, and effort (Kramarski & Mevarech, 2003).

7. Peer- and Self-Assessment (PASA): This strategy allows structured opportunities to engage jointly in self-assessment and peer-assessment as a means of refining student self-thought. This strategy is especially useful when students make evaluations based on predetermined rubrics or criteria (Harris & Brown, 2013).
8. Problem: A situation is "only a problem if you don't know how to go about solving it" (Schoenfeld, 2016, p. 41). Real-world problems are often ill-structured and require solvers to sift through information that is incomplete or poorly understood (Simon & Newell, 1971).
9. Problem-Solving: Two definitions for problem-solving were developed in collaboration with participating teachers. The first definition, which was used in discussions among teachers, stated that problem-solving is "the goal-oriented steps that one takes to solve a problem." A second student-friendly definition stated that problem-solving is "the steps you take to figure out something you don't know."

CHAPTER II

REVIEW OF SUPPORTING SCHOLARSHIP

Nature of Problems

Much of what passes for problem-solving in today's classroom is rooted not in the solving of problems, but in the application of concepts. Schoenfeld (2016) identified two crucial qualifiers for determining if a particular task is truly a problem. First, a problem "is only a problem if you do not know how to go about solving it" (p. 41). He asserted that "exercises" are a more accurate description of those questions that can be answered in a routine and familiar manner. Second, problems must be of interest to the solver. If no one has an interest in solving a particular problem, then it is probably not a real problem. Schoenfeld's writing focused on mathematics, yet this distinction is especially relevant to the solving of real-world problems that involve complex and ill-structured elements (Byun, Lee, & Cerreto, 2014) not often found in most mathematics applications.

Problem-Solving Theory

The theoretical development of problem-solving processes and models have deep roots in real-life applications. Modern problem-solving was heavily influenced by the Gestalt theory, which deals with grouping elements by underlying structure or as a unified whole (Duncker & Lees, 1945; Heider, 1977). Polya (1945), and later Schoenfeld (1985), added structure to many Gestalt ideas as they proposed problem-solving models that provide steps the solver can use to move from the chaotic clutter of an unstructured problem to a justified solution (Voskoglou, 2010). This structure provides a framework for solving complex problems across a wide range of applications.

Yet in many classrooms, these processes and models are often only applied in simplistic word problems. Polya's (1945) famous four-step method for solving problems–Understand the Problem; Devise a Plan; Carry Out the Plan; Look Back–is commonly used by mathematics students when approaching word problems (Shirali, 2014). As students learn to implement the problem-solving method on well-structured tasks, they lose the ability to deal with the messy, ill-structured problems these models were developed to address.

Difficulties in Problem-Solving

Authentic problem-solving in mathematics is a complex process that requires students to use content knowledge in diverse and ever adapting situations. Though often performed within a limited scope that largely mirrors standardized testing, meaningful problem-solving requires a thoughtful approach. A review of the literature highlighted several difficulties faced by students as they engage in the problem-solving process. Often cited in the research were simplistic approaches to complex problems (Dweck, 1986), concept application that is devoid of context (Onslow, 1991), overuse of teacher modeling, and weakness in reasoning and justification (Carpenter, Franke, & Levi, 2003). These problem-solving approaches, which seem to stem more from the nature of problems used in elementary classrooms than a deliberate instructional focus, make the development of metacognitive and problem-solving skills difficult.

A common challenge for young problem solvers stems from how they learn to engage with challenging problems. Students tend to approach problems in mathematics in a "mindless, superficial, and routine-based way" (Verschaffel, De Corte, & Vierstraete, 1999, p. 265). Often, the work of students "consists almost entirely of memorizing presented facts or applying formulas, algorithms, or procedures without attention to why or when it makes sense to do so" (Stein, Grover, & Henningsen, 1996, p. 457). Possibly indicative of teaching practices geared toward success on high-stakes tests, students often view problem scenarios as a series of small tasks by which to use an operation rather than as a potentially meaningful opportunity to apply mathematical concepts. Instead of dissecting problem-solving scenarios to find mathematical relationships, students learn to mine problems for structural cues and clue words. While beneficial in increasing accuracy on simple problems (Baars, Vink, van Gog, de Bruin, & Paas, 2014), these strategies are largely ineffective when tackling authentic problems set in a world that does not always hold to such uniformity.

The existing research highlights a lack of context as a related factor in the weak development of problem-solving skills. Many students tend to rely on these simple algorithms in place of a more robust and ultimately meaningful context-based model. In essence, children are more likely to simply add or subtract given numbers than to attempt to place the information within a model that represents a real-life application. An essential step in successful problem-solving is the process of building a structured representation of the information given (Zhang & Xin, 2012). The construction of accurate models, mental imagery, and graphic representations indicate a strong understanding of the nuances of a given problem. In light of the previously noted superficial approach, it is understandable that students struggle to connect given information with a construct tied to real-life application.

As students age, the depth and breadth of task scenarios increase. Zhang and Xin (2012) mentioned irregular contexts, ill-defined scenarios, problems requiring background information, and multi-step problems as characteristics of challenging problems. Additionally, while students may appear to demonstrate proficiency with a given concept, these difficult problem-solving tasks often highlight a weakness in applying mathematical knowledge to unfamiliar, yet related situations (Verschaffel et al.,1999). Instead of merely reinforcing a student's ability to apply a mathematical concept, challenging problems have the potential to deepen conceptual understanding and contextual knowledge.

Actions of Strong Problem Solvers

The body of research highlights common actions of students who are adept at problem-solving. A successful problem solver analyzes problem scenarios to assess their understanding of information and implications and identify areas of uncertainty. During this analysis, they create patterns and organize known information and identify unknowns for further exploration. (Loesche, Wiley, & Hasselhorn, 2015). After reframing the problem, the student is able to set goals for the use of known information and resolution of unknown elements. A solution model is developed in what is often a cycle that uses productive failure to explore the problem, adjust focus, and reframe the solution model. Once a solution has been found, adept problem solvers evaluate success in terms of their progress towards predetermined goals and make adjustments as necessary.

Metacognition

Metacognition is the process of thinking about one's thinking. Flavell (1979) first used the term metacognition to describe the "monitoring of a wide variety of cognitive enterprises [occurring] through the actions and interactions among four classes of phenomena: (a) metacognitive knowledge, (b) metacognitive experiences, (c) goals (or tasks), and (d) actions (or strategies)" (p. 906). Along with problem-solving, metacognition has been described as "the two most overworked and least understood buzzwords of the 1980s" (Schoenfeld, 2016, p. 3). As the study of metacognition spread from the realm of psychology to the field of education, the theory took on several varied and sometimes confusing definitions. Today, most educators associate metacognition with self-regulation and self-assessment (Kramarski & Mevarech, 2003). These two aspects of metacognition are most applicable to the educational setting because they are composed of concrete actions that are routinely taken by successful problem solvers.

Within the context of problem-solving and critical thinking, metacognition is often framed as a three-phase process consisting of awareness, monitoring, and regulation. The awareness phase includes analysis of the task structure (Halpern, 1998) and cognizance of cognitive processes (Schraw & Moshman, 1995). Students can utilize past experiences and the implicit and explicit information embedded within a task

(Haller, Child, & Walberg, 1988) as a basis for analyzing the structure of a task and begin to compensate for areas of uncertainty or perceived weakness.

Goal setting and task planning are the concrete actions that emerge from the awareness phase and serve as guide and benchmark for the self-monitoring and regulation that follow. Students typically deal with problems that are superficial. At the elementary level, these problems are usually designed to give students practice applying a designated skill. While structured around a real-life application, these problems seldom offer opportunities for higher-level thinking. Thus, many problem-solving activities in elementary classrooms lack opportunities for goal setting, task planning, and self-analysis. Researchers describe effective tasks as authentic, open-ended, discussion prompting, and having a degree of uncertainty (Reusser, 1988; Shielack, Chancellor, & Childs, 2000; Stein et al., 1996) Among the best problem-solving and critical thinking tasks are those that are multifaceted or made up of multiple layers. In these problems, each new element prompts deeper understanding and a chance to analyze success, reformulate goals, and adjust the plan (Stein et al., 1996). This multifaceted nature of an effective problem is key to a problems' ability to prompt the development of metacognitive skills.

Metacognitive skills develop from the deliberate use of self-thought processes over many years. For successful students, metacognitive skills grow naturally through "situations that stimulate a lot of careful, highly conscious thinking" (Flavell, 1979). According to Kuhn (2000), the transition to metacognitive thinker begins with "young children's dawning awareness of their own and others' mental functions" (p. 180) and "follows an extended developmental course during which it becomes more explicit, more powerful, and hence more effective, as it comes to operate increasingly under the individual's conscious control" (p. 178). The flickering of awareness in the young child "lies at one end of a developmental progression that eventuates in complex metaknowing capabilities not realized before adulthood" (p. 178). Metacognitive training in the mathematics classroom seeks to shorten this developmental progression through explicit lessons aimed at bolstering essential metacognitive functions in problem-solving situations.

Metacognition is rarely emphasized in the traditional classroom, but researchers cited several benefits in discussing the apparent positive effects of instruction in metacognition. Labuhn, Zimmerman, and Hasselhorn (2010) pointed to the increased responsibility and motivation for learning that comes with a focus on self-regulation. Metacognitive instruction also provides a fresh perspective for examining the differing needs of all learners in a classroom (Paris & Winograd, 1990). Within the classroom, a focus on personalization and differentiated instruction can have a positive effect on critical thinking and problem-solving by providing all students with learning goals and tasks that provide an appropriate degree of challenge (McCoach, Gubbins, Foreman, Rubenstein, & Rambo-Hernandez, 2014). Conversely, one could argue that the addition of metacognitive instruction increases the effectiveness of a curriculum by reinforcing the personalization found in a differentiated classroom.

The development of a habit of metacognitive monitoring is also cited as a benefit of this type of instruction. The continual analysis of problems and the formulation of strategies is a foundational part of dissecting a complex problem (Jacobse & Harskamp, 2012). Additionally, students with strong metacognitive skills gain the capacity to regulate their cognition (Mevarech & Amrany, 2008). Thus, because students engage in learning tasks with an awareness of their cognitive processes, they are better able to adjust and direct their thinking strategies to meet specific goals.

Calibration of Metacognition

Calibration is an important indicator of metacognitive proficiency. Within the context of metacognition, calibration is used to describe the accuracy of a student's perception of tasks, information, feedback, and their performance and ability. Calibration is an essential element of successful self-regulation (De Grez, Valcke & Roozen, 2012; Glenberg & Epstein, 1985; Winne, 2004; Zimmerman 2002) In multiple studies, low calibration was linked to limited success in metacognition (Labuhn et al., 2010; Mevarech & Amrany, 2008; Sherer & Siddiq, 2014). The literature highlighted two distinct aspects of metacognitive calibration in developing problem-solving and critical thinking skills.

The first aspect of calibration involves ones' thoughts about their abilities and performance. Glenberg and Epstein (1985) described this aspect of calibration as the extent to which a student's perception of their ability and actions matches their actual performance. Students with low calibration often fall victim to an "illusion of knowing" brought about by a high level of personal confidence and a low capacity for recognizing "contradictions" within a task (p. 702). This illusion is compounded in the typical elementary classroom where students engage almost exclusively in tasks structured to elicit success.

The second aspect of calibration relates to ones' ability to accurately understand and analyze key parts of a task. Winne (2004) described this aspect of calibration as "the degree to which a learner's judgment about some feature of a learning task deviates from an objectively or externally determined measure of that feature" (p. 467). In the field of mathematics, this type of calibration is closely associated with diagnostic competence. Successful diagnostic competence is defined as "the ability to accurately assess characteristics of individuals, tasks, or programs and their educationally relevant preconditions" (Friedrich, Jonkmann, Nagengast, Trautwein & Schmitz, 2013). While solving a problem, a student must have high calibration to diagnose the complex components of a problem accurately. Diagnostic ability is essential in attaining a high level of calibration between self-evaluation and capability.

Domain Specificity

Of particular interest to the educator is research on students' ability to employ metacognitive skills in other academic content areas. In framing their research, Jacobse and Harskamp (2012) noted the domain specificity of metacognition. Rather than having broad applicability, students' metacognitive skills "may not be directly transferable to another domain" (p. 135). While developing students' metacognition was shown to increase achievement in the specific academic areas targeted, much of the research presented indicates a positive effect within only a small slice of the overall educational program (Kramarski & Mevarech, 2003). While concluding the discussion of their study, Labuhn et al. (2010) wrote, "our findings are subject to contextual constraints and hence not directly transferable to actual classroom settings" (p. 191). In essence, while participating students show growth in metacognitive skills, they may not necessarily see natural applications of those skills in different situations.

In light of the potential for a limited transferability of metacognitive skills, three questions emerge for educators considering metacognition training for students. First, why are students who are trained in metacognition typically only able to apply the skills in academic domains similar to those in which the training took place? Second, is there a way to adjust instruction on metacognition so that it is easier to apply in other situations? Finally, even if this domain specificity can be reduced, do the benefits of metacognitive training justify the time and effort expended by teachers and students?

Metacognition and Critical Thinking

Strategic instruction on the process of critical thinking holds potential for promoting domain transference of metacognitive skills in younger students. Ennis (1989) provided two principles for the transfer of critical thinking skills among domains. These principles stipulate that transfer of critical thinking skills is possible if students have background knowledge that relates to the given task and have received sufficient instruction and practice in applying critical thinking skills in new domains. While Ennis (1989) highlighted the body of research that supports transference of critical thinking skills, he also cautions that demonstrated benefits are difficult to evaluate and provide a limited scope for understanding the transference of generalized critical thinking skills. Despite the scarcity of literature on the practical effects of critical thinking instruction programs, several key elements have been found to be applicable across domains.

Among the critical thinking skills that show a potential for transference among domains are many that are metacognitive in nature. Halpern (1998) found that critical thinkers demonstrate persistence in challenging tasks, proactive use of planning strategies, flexibility, strategic attempts at self-correction, and an accurate perception of potential obstacles to implementation. Additionally, critical thinkers employ "maxims for how to think…like ‘look for a problem's deep structure' or ‘compare both sides of the issue'" (Willingham, 2008, p. 23). These traits align closely with metacognitive self-regulation which takes place in three phases: 1) planning 2) monitoring 3) regulating (Duckworth, Grant, Loew, Oettingen & Gollwitzer, 2011; Lodewyk, Winne, & Jamieson-Noel, 2009; Winne & Hadwin, 1998). Perhaps a key to prompting students to utilize metacognitive processes when engaging in unfamiliar tasks is to teach the metacognitive processes within the context of important traits and actions of a critical thinker.

Motivation and Metacognition

The relationship between metacognitive skills and student motivation frequently appears in the body of literature. With roots in psychology, these two areas of study naturally complement one another. Ames (1992) described the process by which a student determines whether a task merits the expected time and effort. In essence, increasing a student's metacognitive acumen increases their perceptions of a tasks value. This value assigned by the student is usually directly related to their level of motivation.

The existing body of research also highlights the distinction between intrinsic and extrinsic motivation. Deci, Vallerand, Pelletier, and Ryan (1991) described the extrinsic nature of the vast majority of the actions students take while in school. While intrinsic motivation was highly desirable, very few of the actions by students stem purely from these self-generated desires. Rather, it is often the case that behaviors typically viewed as intrinsically motivated are merely a response to compelling and desirable external factors. While this distinction may seemingly be of only tangential importance to a discussion on problem-solving, it may merit consideration when analyzing the types of problems that students find difficult.

One trait that is often possessed by those with high levels of intrinsic motivation is a positive feeling of self-efficacy. In contrast to students with low self-efficacy, those who perceive their capabilities to be high "approach difficult tasks as challenges to be mastered rather than threats to be avoided." (Bandura, 1997). In fact, "a sense of confidence is a most powerful precursor and outcome of schooling" (Hattie, 2009, p. 47). It is important to note that student implementation of adaptive academic behaviors can decrease when their high perceptions of self are based on nonacademic factors (Shavelson & Bolus, 1982). This discrepancy between perceived and actual capability highlights the importance of strong metacognitive calibration.

Though the existing literature shows mixed support for programs designed to boost self-esteem, the importance of high self-efficacy is supported by "contemporary theories of human motivation, namely, self-determination theory" (Niehaus, Moritz Rudasill, & Adelson, 2012, p. 119). Often implemented to meet social or behavioral goals, self-esteem interventions provide students with opportunities to explore strengths and bolster their relationships with peers. Though these programs are typically presented within the context of increasing positive academic behaviors, the link is often superficial and secondary to a focus on boosting scores on high-stakes tests. While these programs have been shown to increase self-efficacy in the short-term, the nonspecific nature of the interventions often leads to "generalized feelings of positive self-regard [that] may be based on success in nonacademic areas" (Valentine, DuBois, & Cooper, 2004, p. 113). Rather than providing students with lasting confidence in their ability to tackle challenges, these generalized increases in efficacy often are "negated easily by subsequent unsuccessful performances." "Under these circumstances, high levels of self-esteem theoretically may diminish rather than increase adaptive efforts in the academic realm" (p. 113). Thus, approaches that are not tied to classroom and content applications seem to be of limited use in the elementary context.

Programs that have been most successful at developing student self-efficacy are those designed to increase achievement while also developing a students' self-beliefs. These efforts, which provide students with tasks that increase in difficulty as the student gains knowledge and experience align with the recommendations for increasing problem-solving capacity as well as building metacognitive skills. This two-fold approach benefits from a mutually supportive relationship as students with high self-efficacy are more apt to implement metacognitive strategies (Pintrich & DeGroot, 1990), and those who implement effective strategies are more likely to have a high level of self-efficacy (Schunk, 1989). This relationship highlights the importance of teaching the use of metacognitive skills within the context of the concrete steps taken by proficient problem-solvers.

Determination and Grit

Closely related to self-efficacy is the idea of fostering determination or "grit." Grit is "the quality that enables individuals to work hard and stick to their long-term passions and goals" (Perkins-Gough & Duckworth, 2013, p. 14). Duckworth and Quinn (2009) found grit to be a higher predictor of success than IQ. The quality of persistence, while seemingly innate in some students, is typically developed intentionally over an extended period (Duckworth & Yeager, 2015). Though challenging to assess, and often overlooked in discussions of student success, grit can serve as a powerful indicator of competence in problem-solving and critical thinking.

The actions tied to grit: self-regulation, contextual task analysis, goal orientation, and reflection, are sometimes described as falling within a set of noncognitive abilities. These abilities are many of the same metacognitive processes that are related to increased capacity for problem-solving (Ames, 1992; Niehaus et al., 2012; Perkins-Gough & Duckworth, 2013). Pogrow (1988) highlighted the importance of exposing learners to challenging material in a manner that allows for "controlled floundering" (p. 83). In essence, students must be given tasks that pose a significant challenge and foster sustained effort. Elements of the "controlled flounder" include occasions to struggle, evaluate, regroup, and retry without being rescued by the teacher. These structured opportunities to miss the mark and then see the activity through to a successful end are thought to develop grit by providing “very effortful practice on things [the student] can’t yet do” (Perkins-Gough & Duckworth, 2013, p. 19). In critiquing the grit narrative, Socol (2014) argued that rather than simply providing structured opportunities to fail, teachers should give children the "support, time, resources, and love which make persistence possible” (p. 11). At the elementary level, grit-building instruction might best be implemented along with specific instruction and feedback designed to develop metacognitive and problem-solving skills.

Closely associated with the idea of grit is that of mindset. According to Dweck (2006), students viewed their capacity to accomplish a goal or task through either a fixed or a growth mindset. Students with fixed mindsets believe that their “qualities are carved in stone” (p.6). The growth mindset is “based on the belief that your basic qualities are things that you can cultivate through your efforts” (p. 7). In practice, the belief that improvement is possible given enough practice and effort is seen in the metacognitive processes of goal setting and goal striving, which occurs when one strategically implements actions to meet a goal while simultaneously working to reduce factors that could inhibit success (Gollwitzer, 1999). These proactive actions are an important part of the metacognitive and problem-solving process.

Many struggling learners are inclined to give up when dealing with tasks they feel are too difficult. Rather than fail based on low academic ability, students sometimes engage in self-handicapping behaviors that will allow them instead to be perceived as an underachiever (Valentine et al., 2004). Perhaps instruction in skills that characterize the growth mindset—embracing challenges, persistence in difficult tasks, and effective use of feedback (Dweck, 2006; Hochanadel & Finamore, 2015)—could lead to increased performance in the goal setting and self-regulation aspects of problem-solving. What is not discussed in great detail in the literature is whether this determined behavior stems naturally in an individual who has these metacognitive skills. Or, are students who are naturally ambitious and determined able to develop these skills to further their goals. Possibly a more in-depth look at this relationship could add insight into the design of an intervention to teach metacognitive skills.

Classroom Structure

A final theme that stood out in the review of the literature is the significant impact that classroom structure and teacher actions have on student self-regulation and motivation. Glasser (1990) wrote "effective teachers manage students without coercion," before describing the coercive nature of traditional classroom practices (p. 427). If a central goal of mathematics instruction is to develop complex thinkers, what responsibility do educators have for designing tasks that are meaningful and engaging? At what point do student effort, determination, and self-regulation cease to be within the students' realm of control? Simply put, to what extent should educators expect students to engage with problems that are not of interest or perceived relevance to students?

The existing body of literature is largely silent on the extent to which classroom structure affects student metacognitive development. Two studies were found that examined classroom structure and metacognition, but both are only tangentially related to the topic of fostering problem-solving and critical thinking skills. Salmon, Rossman, and DiPinto (2012) described the positive effects that teachers with high metacognitive skills have on classroom structure and student success. These teachers plan authentic learning experiences that are scaffolded to provide students with opportunities to think reflectively and adapt to challenges. Andersen (2004) examined the potential for activities that develop cognitive skills in the drama education setting. He provided suggestions for advancing metacognitive skills through situated learning. Snyder, Nietfeld, and Linnenbrink-Garcia (2011) highlighted the possible impact of classroom environments on metacognitive skill development as an area for future research. However, their study used classrooms that were grouped homogeneously by ability and thus were unable to make generalizations on the impact of the structure.

In the absence of relevant literature, it seems beneficial to highlight some teacher practices and instructional strategies that hold promise in developing student metacognitive skills. While the literature highlighted many elements of a successful classroom, three instructional practices stood out as being particularly applicable to developing metacognitive skills in the area of problem-solving and critical thinking. These practices and strategies closely align with the three phases of metacognitive self-regulation: 1) planning 2) monitoring 3) regulating.

The first classroom practice that was shown to bolster metacognition in problem-solving involves the use of authentic learning tasks. Ball and Washburn (2001) linked the use of "hands-on" and "applied" teaching approaches to the development of a students' ability to evaluate difficult situations. These authentic situations provide students with an opportunity to think through complex tasks, reformulate theories, and judge the accuracy of their perceptions (Onslow, 1991; Tay 2015). Additionally, meaningful tasks allow students to operate from within a framework where natural uncertainty and ambiguity are often present. Working within a context where everything does not necessarily fit perfectly improves a student's ability to analyze tasks and make determinations on the relevance and reliability of given information. (Lampert, 1990; Stein et al., 1996) Also, a classroom environment that is rich in authentic, hands-on learning is highly motivating to students, and likely to spur learners to take risks, reflect on successes and failures, and make adjustments mid-course (Gregory & Kaufeldt, 2015; Reusser, 1988). In the elementary classroom, authentic learning tasks may be the only opportunity for students to exercise many essential metacognitive skills.

Another instructional strategy that impacts student metacognition is the frequent use of targeted feedback. Kramarski and Zoldan (2008) "call for a metacognitive culture, in which making errors is acceptable" (p. 148). Hattie (2012) recommended "welcoming error" before adding "succeeding at something you thought was difficult is the surest way in which to enhance self-efficacy and self-concept as a learner" (p. 58). It is through these errors that students can "self-question and analyze errors", "make connections", and "formulate an action plan on how well they understood the material" (Kramarski & Zoldan, 2008, p. 148). "Feedback about the qualities of work and feedback about the process of strategies used to do the work are most helpful" (Brookhart, 2008, p. 4). Additionally, feedback that "draws students' attention to their self-regulation strategies" is beneficial when it allows them to see that they are more successful through hard work (p.4). The frequent use of purposeful feedback, especially in a classroom that welcomes errors as a springboard for deeper learning, has the potential to hone calibration and bolster the independent use of metacognitive skills.

The final instructional strategy that has been shown to foster student metacognitive growth is the routine use of peer- and self-assessment (PASA). Engaging students in the joint process of PASA provides them with structured and teacher-guided opportunities to gauge their academic performance against an objective set of criteria. This practice can be especially effective in developing self-regulation when used in situations where students must make justifications or evaluations based on predetermined rubrics or criteria (Harris & Brown, 2013). Though most students require practice to develop PASA skills, generally the assessments of experienced students do not significantly vary from those of the teacher (Falchikov & Goldfinch, (2000). The high degree of similarity between experienced student and teacher evaluations suggests that PASA enhances student ability to employ metacognitive strategies.

Guided Instruction

Guided instruction is an adaptable approach that allows teachers to shift responsibility for learning to students by strategically guiding student work on learning activities. While there are some differences in approach, a review of the literature emphasized three main components of guided instruction. First, teachers rely heavily on the robust cycle of formative assessment and student observation to make individual instructional decisions for each student or group. Second, teachers employ a wide range of strategies such as questioning, cues, modeling, prompts and direct explanations to facilitate learning. Finally, teachers work to shift the responsibility for learning to the student by providing just enough assistance to allow students to move to the next level of understanding (Carpenter, Fennema, & Franke, 1996; Fisher & Frey, 2010; Mayer, 2004). With a deliberate focus on continuous assessment and brief ongoing interactions, guided instruction provides a useful instructional framework for the controlled development of problem-solving and metacognitive skills.

The use of diminishing supports is an important aspect of the gradual release model found in guided instruction. Fisher and Frey (2010) emphasized a use of scaffolded support that is tailored to the specific needs of the student or group. A scaffolded approach allows students to lean on teacher provided structures, cues, and models while they begin to assume responsibility for their learning (Maloch, 2002). Mayer (2004) focused on structure as he described fully guided instruction. In his depiction, students receive brief, highly structured instruction, modeling, and feedback as they progress towards their learning goals. Mayer (2004) highlighted the constructivist nature of learning yet sets this approach in contrast to discovery learning by emphasizing the structured intervention in developing students' understanding. Carpenter et al. (1996) emphasized the role of the teacher in providing guided instruction. Their model begins with the teacher's experience and expertise as the starting point for planning instruction. The teacher analyzes the concept or problem and past student performance to understand student thinking. They are then able to informally question students, model concepts, and intervene as needed.

Conclusions

Metacognitive skills have been shown to play an important role when solving complex problems. Existing research shows that metacognitive training programs can be effective in boosting problem-solving skills. Training students to analyze and monitor their effectiveness when solving math problems could be an effective use of time and resources. While domain-specific training is generally very successful, further research could lead to instructional strategies that develop a metacognitive mindset that transcends all areas of school, work, and social life.

Additionally, an analysis of problem-solving and metacognition is bolstered by the existing research on student motivation. The metacognitive skills that are hallmarks of a determined learner: self-regulation, self-reflection, thoughtfulness, and goal-oriented action, are closely tied to motivation. The literature points to the importance of a classroom and instructional design that provides authentic problems that can be solved in a relatable and authentic context.

CHAPTER III

SOLUTION AND METHOD

Proposed Solution

To develop problem-solving skills, students took part in a nine-week program consisting of lessons that embed metacognitive strategies within Schoenfeld's (1985) problem-solving model. With a favorable outcome, students will have developed an increased capacity for using metacognitive skills in problem-solving situations across content areas. Data in the form of problem-solving assessments, student surveys, classroom observations, semi-structured teacher interviews, and cognitive labs were collected to determine if students' capacity for metacognitive thinking is increasing.

Outline of the Proposed Solution. The proposed intervention consisted of a nine-week problem-solving training program. An intervention schedule with lesson objectives and problem titles are presented in Appendix A. Lessons were based on Schoenfeld's (1985) five-step method of problem-solving: 1) analyze the problem, 2) make a plan, 3) implement the solution, 4) mathematical exploration, and 5) verification. Embedded within each step of Schoenfeld's (1985) method are corresponding metacognitive skills: 1) use knowledge and experience, 2) set goals, 3) take action, 4) use strategies/monitor, and 5) evaluate success (Flavell, 1979). Figure 1 includes a conceptual framework for the intervention highlighting the integration of the problem-solving model and metacognition within the context of guided instruction.

Over the course of nine weeks, the lessons built upon each other to guide students through increasingly complex applications of problem-solving and metacognitive strategies. The first six lessons taught problem identification, strategy planning, implementing solutions, adjusting approaches, and evaluating success. The final three lessons teach problem posing and redefining problems based on new information.

All third- and fourth-grade students participated in one 45-minute lesson a week for nine weeks for the problem-solving program. Lessons were conducted on Thursdays for third grade and Fridays for fourth grade during the students' computer lab time. The lessons were co-taught by the researcher and the mathematics teacher. Each session centered around one open-ended problem scenario and began with a ten-minute mini-lesson. Students were presented with the problem after the lesson. Co-teachers utilized guided instruction to prompt students as they worked in small groups to analyze the problem and develop a solution. Each session ended with a five-minute review and debriefing.

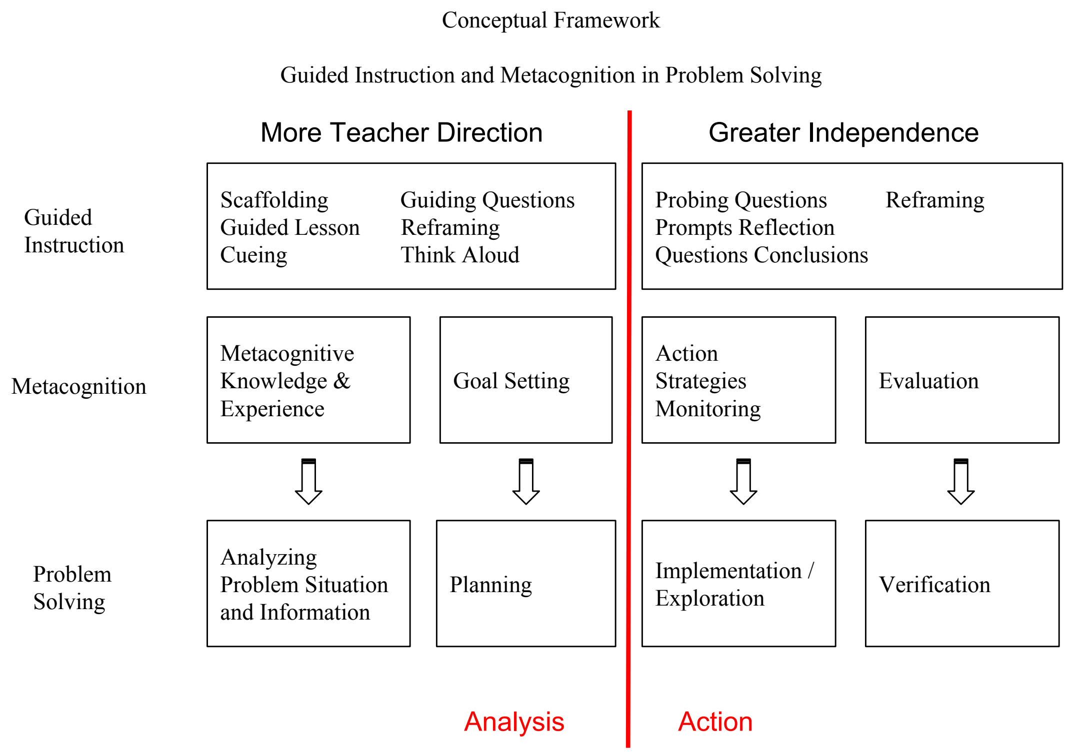


Figure 1. Conceptual framework for proposed intervention.

Study Context and Participants

Study Context. The intervention and data collection for this study were implemented as a part of the mathematics class. The problem-solving lessons took place during an existing intervention period and were integrated into the broader mathematics program. I work in each classroom on a regular basis in my role as a campus interventionist and took care to specify that I was in their class to work on problem-solving practice while engaged in study-related activities. Though information attained in the course of the study was used by teachers to make educational decisions, no activities or student work products were used in classroom assessment, and no grades were given for activities associated with this intervention. As the teachers worked to incorporate elements of the problem-solving intervention into their regular classroom instruction, they began to utilize problems that were similar to those used in the study. Students received grades for some of these teacher-created assignments.

Participating Students. Due to the small student population, participants for this study were all third- and fourth-grade students. There were 21 third grade students and 20 fourth grade students (95% are White; 5% are Hispanic), which closely resembles the ethnic makeup of the campus as a whole. Approximately 45% of these students are economically disadvantaged. Additionally, a nested sample (Onwuegbuzie & Collins, 2007) of three students from each class participated in cognitive labs. These participants were chosen using purposeful criteria in collaboration with the teacher to select one proficient, one typical, and one struggling problem-solver in each class. These criteria were used to elicit information on the thought processes of students with a wide range of abilities.

Participating Teachers. The participating third- and fourth-grade mathematics teachers both volunteered to take part in the study. The teachers have varying degrees of experience in education. One teacher has taught in the same position for the past ten years while the other is in the first year in a new position. Both teachers have been with the district for more than six years. Colleagues described both participating teachers as highly effective and engaging teachers who set high expectations for their students.

Proposed Research Paradigm

A convergent mixed methods design was used in this study. This design was selected because it allows for the contemporaneous collection of both quantitative and qualitative data (Creswell & Plano Clark, 2011; Onwuegbuzie & Collins, 2007). With this approach, the quantitative data and qualitative data were analyzed independently and then mixed at the conclusion of the study. Figure 2 shows the use of the convergent mixed methods design in this study.

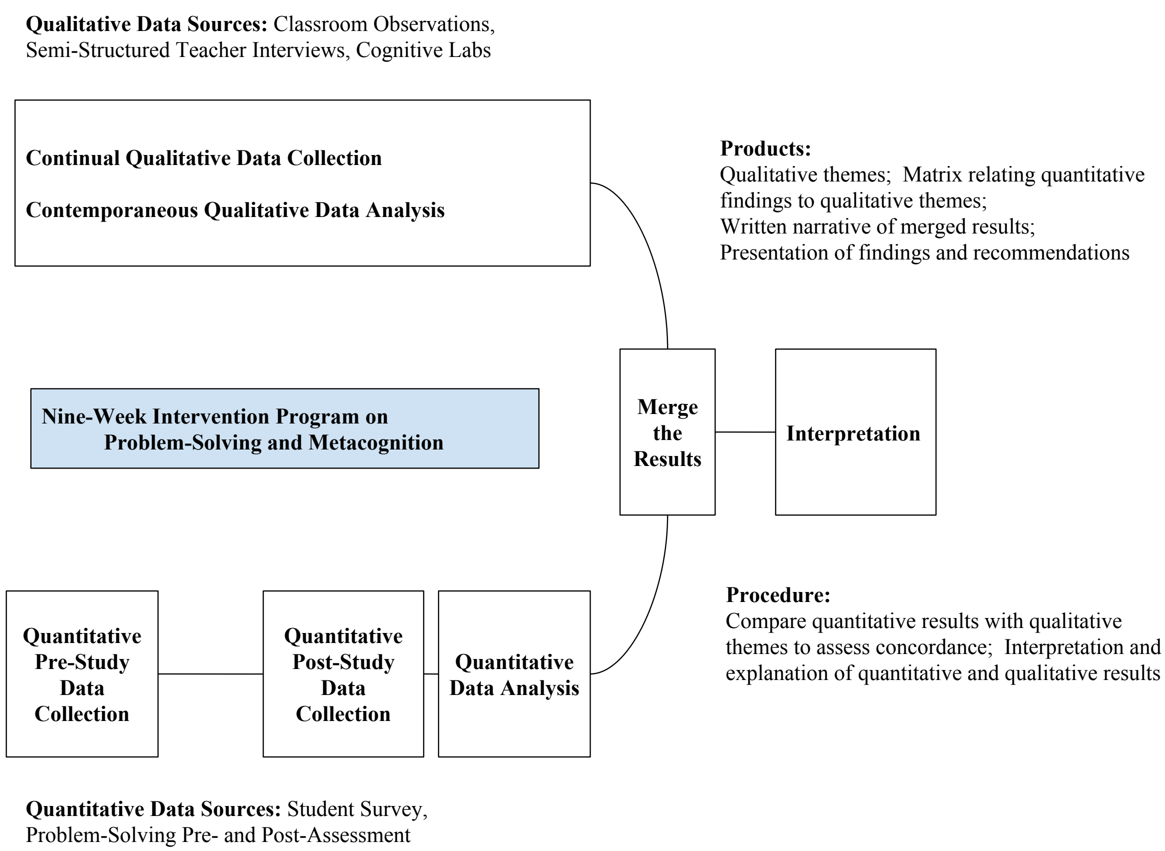


Figure 2. *Research paradigm: Convergent mixed methods design.*

Data Collection Methods

Quantitative Data. Quantitative data were obtained from 3 instruments. Instrument 1 was a student survey that was designed to provide insights into the implementation of metacognitive strategies and used pre and post to estimate the impact on student learning (See Appendix B). The survey utilized a 5-point Likert scale ranging from 1 (Never) to 5 (Always). Instrument 2 was a problem-solving pre-assessment that was designed to provide insights into student problem-solving ability before the intervention (See Appendix C). Instrument 3 was a problem-solving post-assessment that was designed to provide insights into student problem-solving ability after the intervention (See Appendix D). Data for the pre- and post-assessments came from a four-point rubric ranging from beginning to advanced (See Appendix E).

The use of student surveys fulfilled three important data needs. First, the student survey provided baseline data on student problem-solving and metacognitive skills that could be discussed with the teacher at the outset to help frame our understanding of the students. Second, the student survey provided data showing changes in student perceptions over the course of the study. Third, the student survey provided data on individual students that could be used in conjunction with qualitative information to develop a more insightful final narrative.

The problem-solving pre-test and post-assessments were used to provide quantitative data on student problem-solving ability. The problems utilized on the assessments were created in collaboration with teachers to present an open-ended task that was developmentally appropriate while also being complex enough to require deep thinking. The scoring rubric was designed to provide data on six key aspects of problem-solving: 1) identifying important information 2) restating the problem 3) creating a plan 4) exploring possible solutions 5) presenting a solution 6) evaluating the solution.

Qualitative Data. Three types of qualitative data were collected during the study. First, weekly classroom observation sessions were conducted by the researcher and utilized throughout the study to collect anecdotal information about problem-solving and metacognitive skills use. Second, brief semi-structured teacher interviews were conducted three times during the study to gain an understanding of the teacher's perspective of the effectiveness of the program and changes in student problem-solving ability. Third, because the use of metacognitive strategies was difficult to measure in a whole group setting, cognitive labs were conducted with three students in each class to gather data on their use of metacognitive skills when problem-solving.

Classroom observations were used to gain information about the characteristics of student problem-solving and the use of metacognitive strategies in the classroom. Additionally, information about the teacher's use of guided instruction and problem-solving instruction was collected. Observations took place during the portion of the mathematics block when students were solving problems related to the mathematical concepts covered in class. For these observations, I assumed the role of "Participant-As-Observer" (Gold, 1958), which was most appropriate because I was observing in classrooms of colleagues and students with whom I have meaningful ongoing working relationships. While the majority of the observation was used to collect qualitative data, a ten-minute segment was set aside for conducting a brief analysis of student behaviors that were relevant to the study.

A semi-structured interview format was selected because it allowed for flexibility while maintaining a focus on those aspects of the study that most closely supported the guiding questions. Initially, I intended on conducting teacher interviews at a scheduled time after school. As the study progressed, many of the questions included in the interview guide were discussed informally in the course of the work I was doing alongside the teacher. Rather than repeat the semi-structured interview in its entirety, I began taking notes of our informal discussions and used the scheduled interview time to ask questions that were not touched upon in the informal discussions and seek clarification or more information about the earlier conversations.

Cognitive labs were selected as a means of gaining insight into the thinking of students as they worked on grade-level problems. Because one cannot directly observe a student's thinking process and use of metacognitive strategies, the cognitive labs provided an opportunity to assess the problem-solving and metacognitive skills of students. Problems for the cognitive labs were modeled after questions used at the time in classroom instruction and were selected from extension activities that are a part of the math curriculum. Cognitive labs took place on a bi-weekly basis which allowed for the collection of 4 labs with each student.

Instruments

Quantitative Instruments. The student survey and problem-solving pre- and post-assessments were collaboratively designed with mathematics teachers during the problem framing and intervention planning process. Both instruments were designed to provide data on specific areas of problem-solving and metacognitive thought that were noted while collecting data on the problem. An effort was made in the creation of each instrument to develop a document that would provide reliable data within the campus context. Because these instruments were designed to meet specific campus data needs, adjustments would likely be necessary before implementation in other settings. All instruments were field tested during the previous year with fourth and fifth-grade students in an attempt to mitigate potential problems.

The student survey instrument was designed to measure areas of concern that emerged in the problem framing process and through a review of the literature (Pazzaglia, Stafford, & Rodriguez, 2016). The survey creation followed the twelve-step Questionnaire Development Steps outlined by Czaja and Blair (2005). The initial survey consisted of 48 questions. During the development of the survey, many questions were removed because they were unclear, repetitive, or deemed unnecessary. Additional questions were removed after consultation with members of the ROS committee. The remaining questions were then rewritten in a kid-friendly language. A five-point Likert scale was selected to allow students a broad range of responses.

Two parallel tests were created for the problem-solving pre- and post-assessments. Both assessments consisted of an open-ended mathematics task that were best solved with a similar approach. Because the pre- and post-assessment tasks could be solved using the same strategy, students were not given the results of the pre-assessment. Likewise, the solutions were not discussed with students until after they completed the post-assessment. These tasks were cross-referenced to the TEKS to ensure that all skills that might be needed to solve the problem were previously taught. The pre- and post-assessments were reviewed by mathematics teachers on campus and field tested with older students to avoid exposing potential participants to the tasks.

The assessments were evaluated using a problem-solving rubric that was developed using a series of statements teachers in which they described what they thought made a good problem-solver. I then examined these statements within the context of the literature on problem-solving in the classroom. A list of six elements of problem-solving was created, and criteria were developed for each. In an attempt to avoid creating another series of steps that students simply follow, the problem-solving rubric emphasized the metacognitive actions that were associated with each concrete step of the problem-solving method. While the rubric was necessary to analyze student problem-solving, an effort was made during the intervention to teach problem-solving as a holistic process in which each broad step represented a method to guide student thinking rather than a set of superficial steps to solve typical word problems.

Justification of Use of Quantitative Instruments. With its small scale and quality improvement nature, the quantitative methodologies often found in larger studies are not necessarily appropriate for this project. Of reliability and validity of the quantitative data for this study, only estimates of construct validity may be impacted by relatively small sample size. However, the quantitative data sources provide valuable information about the effectiveness of the problem-solving program. Because this study is a quality improvement project, results are not generalizable beyond the campus level. Thus, concerns about the limitations of the quantitative data seem to be overshadowed by its potential contribution to the understanding of the success of the program within the campus context.

After consideration of these limitations, the quantitative instruments were developed to provide additional information on changes in student perception and problem-solving ability. Because no control group existed, the quantitative analysis is not intended to demonstrate the effectiveness of the intervention. Rather, these data were used to provide a measurable indicator of changes in perception and ability that was examined alongside the qualitative data during the interpretation phase.

Despite the limitations on generalizing the results beyond the local context, efforts were made to ensure that the quantitative results were understandable and able to be examined within the context of the broader body of literature. Thus, both effect size (ES) and confidence intervals (CIs) were reported for each composite category of the pre- and post-assessment student surveys. The sixth edition of the publication manual of the American Psychological Association (APA) advises that "it is almost always necessary to include some measure of effect size in the Results section" (APA, 2011, p. 34).

Additionally, a review of the literature highlights the importance of effect size reporting along with the use of CIs in framing a discussion of the quantitative results. First, effect size provides a "means for understanding the practical importance of the results" (Capraro & Capraro, 2002). Second, the reporting of effect size provides a basis for comparing the results of this study with results with data reported from similar studies (Fritz, Morris & Richler, 2011). Furthermore, the inclusion of CIs "promotes the 'meta-analytic thinking' [that is] so critical to informed research practice" (Capraro & Capraro, 2003, p. 556). Finally, "The reporting of effect sizes and CIs allow for the rigorous testing of theory by evaluating the persistence and resilience of results across various samples from various geographical regions" (Capraro, 2004, p. 60).

Qualitative Instruments. An observation protocol (See Appendix F) was created to guide the weekly classroom observations and was used to organize a description of observations and reflections. An interview guide was also developed to frame the semi-structured teacher interview. All interviews were recorded and transcribed, and transcripts were reviewed by the teacher to ensure accuracy (Stake, 2010). An administration guide was developed to conduct cognitive labs with students. This three-part guide consisted of a verbal record, a retrospective record, and section for researcher follow up and clarification.

The observation protocol was developed to provide structure and focus to the classroom observations. The protocol was three pages long and has four parts. Part one consisted of descriptive and reflective notes about the teacher and classroom instruction, with specific emphasis on characteristics relevant to the study. Part two consisted of descriptive and reflective notes about students and group interactions, with specific emphasis on problem-solving and metacognitive processes. Part three consisted of a chart for counting the occurrence of relevant student behaviors during a ten-minute period at the end of the observation. Part four consisted of a section for new questions and ideas for further observation.

The semi-structured interview guide (See Appendix G) for teachers consisted of five questions that were selected to elicit the teachers' thoughts on the intervention, student problem-solving, and the use of guided instruction. On the advice of the committee, the number of questions was reduced to five to eliminate redundancy and allow for a more open-ended discussion. The semi-structured interview guide consisted of the following questions:

1. Tell me about problem-solving in your classroom.

2. How successful are your students at: (discuss relevant aspects of the problem-solving process)

- identifying the problem they are trying to solve?
- making a plan?
- the exploration/solving phase?
- presenting their solutions?
- evaluating their work?

3. How do you feel about guided instruction?

4. What are your thoughts on the problem-solving lessons?

5. Do you have any other thoughts, questions, or concerns that you would like to share?

The cognitive lab protocol (See Appendix H) consisted of three parts. Part one contained the student verbal record and additional researcher observations. Part two contained the student retrospective record and additional researcher observations. Part three contained a section for clarification and notes on follow up discussions. During the cognitive lab, I recorded everything the student said to the best of my ability. The final typed document used a transcript from an audio recording of the cognitive lab to ensure accuracy.

Data Analysis Strategy

Quantitative Analysis. Quantitative sources consisting of student surveys and the problem-solving pre-assessment (See Appendix C) and post-assessment (See Appendix D) were used to provide descriptive data on student perceptions of metacognitive skills and problem-solving performance. The assessments were scored according to the rubric created by teachers and the researcher to assess effective problem-solving. Data for third- and fourth-grade students were scored separately. Student responses for the pre- and post-assessment were scored according to the rubric and transferred to a spreadsheet that contained each student's score by each of the six domains of the rubric. The mean, mode, and minimum and maximum scores were then calculated for each of the six domains to explain the variability of the data.

The Pre-Intervention Student Survey and the Post-Intervention Student Survey (See Appendix B) were analyzed to determine measures of central tendency and variability. Creswell (2012) notes that in the field of education, Likert scale data "is treated as both ordinal and interval data" (p. 176). For this study, data from the pre- and post-intervention surveys were treated as interval data because in theory, the intervals among responses are equal. The decision to use interval data also informed the selection of the descriptive statistics used because methods of analyzing ordinal and interval data differ. The Student Survey used a five-point Likert scale ranging from 1 (Never) to 5 (Always).

Individual survey items were combined to create composite categories that could be analyzed (see table 1). Mean and standard deviation were calculated for each composite category. Additionally, effect sizes and confidence intervals were calculated for each category to determine the practical significance of changes in perception. The results for each category were also analyzed using the chi-squared test to determine the significance of the post-intervention survey results.

Effect sizes were calculated to provide an indicator of the practical significance of changes noted from the pre- and post-survey results. Fritz et al. (2011) advised that "when examining the difference between two conditions, effect size based on standard differences between the means are commonly recommended" (p. 3). Thus, Cohen's *d* was utilized to calculate the effect size for each composite category of the pre- and post-assessment survey. Effect sizes values were interpreted in terms of the magnitude of the effect to likely impact the average participant in some practically important way. These values provide a consistent means of comparing the practical significance of results. Cohen (1992) stated that his "intent was that the medium [effect size] represent an effect likely to be visible to the naked eye of the careful observer" (p. 156).

Confidence intervals provide a range within which the true value for a population would be expected to fall. Confidence intervals are framed as a percentage of the time that a population's "value will be within the range of the interval" (Creswell, 2012, p. 194). Results for each composite category of the student pre- and post-intervention study were reported using a 95% confidence interval, which means that the true value would be expected to fall within the given range 95% of the time.

Table 1

Student Survey Statements Arranged by Composite Category

Category 1: Understanding the problem
I can understand what a problem is asking.
I am really good at picking out important information
Category 2: Planning
I know what strategies to try when I get stuck on a problem.
I have trouble coming up with a plan
Category 3: Solving problems
I am good at problem-solving.
I can solve tough problems on my own.
I get frustrated when I have a hard time solving a problem.
Category 4: Evaluation
When my answer is not correct, I look back at my work to find mistakes.
Sometimes I know the answer, but I have a hard time explaining why it is correct.
I can always explain my solutions in a way that other people can understand.

Qualitative Analysis. Qualitative data were analyzed using a constant comparative method. This method allowed for the development of the qualitative narrative by a systematic analysis of the transcripts from teachers and students plus the cognitive labs, observational and anecdotal information, and supporting documents. The computer program Atlas.ti was used in the qualitative analysis process. This qualitative analysis software was selected to manage the large number of documents that were analyzed. Sources of qualitative data consisted of field notes from intervention lessons, classroom observations, semi-structured interview responses, and cognitive labs. These data were analyzed for information that could help answer the three overarching research questions.

This analysis consisted of coding notes and transcripts, developing categories, comparing elements within each category, incorporating categories, and developing themes (Boeije, 2002; Glaser & Strauss, 1967; Stake, 2010). Documents were inputted into the software and coded on a weekly basis to allow for ongoing analysis. However, the study design allowed for the development of additional questions and lines of inquiry, so codes, categories, and themes were not determined before beginning the contemporaneous analysis (Creswell, 2014; Stake 2010).

Starting from scratch, I created codes that I felt accurately captured important insights, implications, and interpretations of the information contained within the documents that were analyzed qualitatively. Over time I began to group similar codes within broader categories when frequently used codes appeared to be related. Next, multiple categories could be grouped within a handful of distinct themes around which the emerging qualitative narrative was developed (Creswell, 2014; Creswell & Plano Clark, 2011; Stake, 2010).

The status of codes and categories was most flexible during the middle three weeks of the intervention as the contemporaneous narrative took shape. In some cases, codes were used only one or two times and appeared to be extraneous, irrelevant, repetitive, or imprecise, and were combined with others or deleted altogether. Likewise, some codes were split into two or more distinct codes when one code was being used to describe observations that differed in some way.

Mixed Methods Interpretation

The quantitative and qualitative results were mixed after the data analysis. During interpretation, the quantitative data and qualitative findings were compared to provide a deeper picture of student perceptions and performance. The qualitative findings provided context for understanding the quantitative results. Conversely, the quantitative results were essential in substantiating the qualitative findings. The mixed results are presented in narrative form and also summarized in a matrix highlighting the level of concordance between quantitative findings and qualitative themes. This combined matrix was used to highlight areas of convergence and divergence. Determining areas of convergence was important because they represented points where qualitative findings could be supported (Creswell & Plano Clark, 2011). Areas of divergence were examined to analyze potential bias, review the accuracy of qualitative codes and quantitative instruments, and identify areas for further study. In some cases, certain quantitative data or qualitative findings did not seem to be relevant to the broader body of results. In these cases, the information was not used in the joint interpretation.

After interpretation, the mixed findings were compiled into a joint display that was suitable for presentation to a wide range of stakeholders. Creswell and Plano Clark (2011) describe a joint display as a "table in which the researcher arrays both quantitative and qualitative data so that the two sources of data can be directly compared" (p. 226). The joint display was organized by research question and provided corresponding quantitative and qualitative results along with summarized findings and implications. The mixed data were also described in greater detail in the narrative report.

Timeline

Work on this project began in the Fall of 2016 with problem framing activities and continued until the Spring of 2019. Table 2 includes a timeline of activities related to the development and implementation of this research project.

Table 2

Timeline of Development and Implementation of Study

Phase	Date	Action
Problem Framing and Initial Data Collection	September 2016	Stakeholder Interviews Initial Data Collection
	October 2016	Classroom Observations Focused Interviews Problem Identification
	November 2016	Collaborative Planning of Potential Solutions Presentation of Potential Solutions
	December 2016	Selection of Final Solution
Study Design and Final Planning	January 2017	Intervention Design
	February – March 2017	Selection of Mixed methods Instrument Creation Planning of Intervention Activities
	April 2017	Completion of Record of Study Proposal
	May 2017	Proposal Defended
	June – August 2017	Adjustments to Study and Methodology
	September 2017	Teacher Professional Development
Intervention and Data Analysis	October 2017	Intervention Began with Third Grade Students
	December 2017	Intervention Began with Fourth Grade Students Ongoing Data Collection Contemporaneous Qualitative Data Analysis
	January 2018	Completed Intervention with Third Grade Students Quantitative Data Analysis Completion of Qualitative Analysis
	February 2018	Completed Intervention with Fourth Grade Students Quantitative Data Analysis Completion of Qualitative Analysis
Writing of Results and Findings	March – June 2018	Interpretation of Mixed Qual and Quan Analysis Completion of Written Narrative Presentation of Findings
Creation of Final Report	May 2018 – April 2019	Completion of Final Written Record of Study

Ethical Concerns

The Institutional Review Board at Texas A&M classified this study as a quality improvement project because interactions with participants and access to data sources took place within the context of the researchers work responsibilities. The potential for student and teacher identification was the primary risk to participants. Multiple steps were taken to ensure that no reports or documents stemming from this study included any identifying information. While participation in the problem-solving intervention posed no academic risk to students, every effort was made to ensure that all activities were educationally appropriate, tailored to student needs, and made good use of instructional time.

Privacy and Confidentiality

Given the small size of the campus, the maintenance of privacy and confidentiality was of the utmost importance. Multiple steps were taken to maintain the privacy of all participating students. Though many of the data and documents were accessible in the course of my regular work duties, steps were taken to ensure privacy and confidentiality for all documents.

When at all possible, no student names were used on study documents. In field notes, student names were necessary for clarity, but confidentiality was achieved through the use of pseudonyms during the transcription phase. In the case of student assessments, surveys, and work samples, students were given a random identification number. For convenience, students wrote their name on the work they completed. After collection, the identification numbers were added before the margin with the student name was removed. In some cases, identification numbers were linked to student pseudonyms while analyzing data.

The discussion of work samples and conversations in the written narrative also presented potential opportunities for students to be identified. Often students' personalities shone through. In these situations, student responses and conversations were summarized or paraphrased to mask their identity. Additionally, it was often easy to identify the work of several students by their handwriting. To avoid identification, all student work was described or transcribed in the final narrative rather than shown.

Teacher confidentiality was much more difficult to ensure. With only one mathematics teacher at each grade level, identifying the teacher along with the grade they taught would lead to identification. Pseudonyms were used in the written narrative when possible. At times, it would be possible to infer the grade level by examining the concepts that were covered. In these cases, the participants were referred to as "the teacher" rather than by their pseudonym.

Reliability and Validity Concerns

The Institutional Review Board's determination that the study was a quality improvement project ensures that the results are not generalizable beyond the campus level. The small scale of the study and local generalizability guided the analysis of potential threats to reliability and validity. Potential issues were analyzed within this context and actions were taken in an attempt to find a balance that minimized threats while still ensuring that the study could yield results that were highly relevant at the campus level.

Three potential threats to reliability and validity were identified during the study design phase. The first concern was that my viewpoint as a researcher would cloud the way I recorded and later analyzed elements of the study. Ongoing conversations with participating teachers and opportunities to review field notes were utilized to help ensure that my perceptions aligned with those of the participants. The second concern was that the small population and lack of a control group would make it difficult to determine the extent to which the results could be attributed to the problem-solving intervention. While this problem could not be completely corrected, the mixed methods approach emphasized qualitative methods which were used to provide results that gave a rich description of the changes that occurred. The final concern was that my role as the campus math interventionist could skew results for students I work with regularly. To minimize this concern, I tracked my use of problem-solving instruction within small groups and tried to match it to the instruction found in the classroom.

Two additional threats to validity and reliability emerged as the study was underway. The first concern that emerged during the study was that I had previously worked with several of the students through my role as a reading and math interventionist. At times, students would reference a problem or strategy from lessons that occurred during the previous four years. When this occurred, I made a point to briefly reteach the strategy or explain the problem referenced by the student in an attempt to minimize potential effects from this previous experience. The second concern that emerged during the study was a flu outbreak leading to a high-level of student absences during the last five weeks of the intervention. To alleviate this concern, I met briefly with students who missed intervention lessons and reviewed the problem-solving and metacognitive strategies covered. I also made a point to become more active towards the end of each classroom observation in an attempt to review and reinforce the strategies covered in the problem-solving lessons.

CHAPTER IV

RESULTS

Results

Quantitative Data. Data from the pre- and post-intervention problem-solving assessments were compiled into tables for presentation. Table 3 illustrates the results of pre- and post-intervention problem-solving assessments for third-grade students. Table 4 shows the results of pre- and post-intervention problem-solving assessments for fourth-grade students. Results from the problem-solving assessments are discussed in greater detail in the integrated narrative.

Table 3

Pre- and Post-Intervention Problem-Solving Assessment Results for Third Grade Students

Domain		Mean	Mode	Minimum	Maximum
Identifies important inform.	Pre	1.24	1	1	2
	Post	1.88	2	1	3
Restates the problem	Pre	1.18	1	1	2
	Post	1.65	1	1	3
Creates a plan	Pre	1.59	2	1	2
	Post	2.47	2	2	4
Explores possible solutions	Pre	1.59	2	1	2
	Post	1.53	3	2	3
Presents a solution	Pre	1.59	2	1	2
	Post	2.18	2	1	4
Evaluates the solution	Pre	1.18	1	1	2
	Post	1.59	1	1	3

Table 4

Pre- and Post-Intervention Problem-Solving Assessment Results for Fourth Grade Students

Domain		Mean	Mode	Minimum	Maximum
Identifies important information	Pre	1.24	1	1	2
	Post	1.71	2	1	3
Restates the problem	Pre	1.00	1	1	2
	Post	1.35	1	1	3
Creates a plan	Pre	1.53	2	1	2
	Post	1.94	2	1	3
Explores possible solutions	Pre	1.65	2	1	2
	Post	2.24	2	1	3
Presents a solution	Pre	1.53	2	1	2
	Post	2.06	2	1	3
Evaluates the solution	Pre	1.18	1	1	2
	Post	1.47	1	1	2

Data from student surveys were compiled into tables for presentation. Table 5 illustrates the results of the pre- and post-intervention surveys for third-grade students. Table 6 shows the results of the pre and post-intervention surveys for fourth-grade students. Student survey results are discussed in greater detail in the integrated narrative.

Table 5

Third Grade Pre- and Post-Intervention Student Survey Results

Survey Category		Mean	SD	CI Upper	CI Lower	ES	χ^2
Understanding the problem	Pre	3.18	1.26	2.59	3.72	.27	4.64
	Post	3.47	1.05	3.00	3.94		
Planning	Pre	3.42	1.10	2.92	3.91	.10	3.65
	Post	3.30	1.07	2.82	3.78		
Solving problems	Pre	3.22	1.18	2.68	3.75	.29	9.45
	Post	3.56	1.10	3.06	4.05		
Evaluation	Pre	3.77	1.29	3.18	4.35	.04	1.16
	Post	3.71	1.30	3.13	4.30		

Table 6

Fourth Grade Pre- and Post-Intervention Student Survey Results

Survey Category		Mean	SD	CI Upper	CI Lower	ES	χ^2
Understanding the problem	Pre	3.58	0.77	3.23	3.92	.57	7.66
	Post	4.00	0.69	3.69	4.31		
Planning	Pre	3.16	1.18	2.65	3.69	.06	1.62
	Post	3.08	1.18	2.55	3.61		
Solving problems	Pre	3.29	1.16	2.77	3.81	.17	3.01
	Post	3.48	1.02	3.02	3.94		
Evaluation	Pre	3.56	1.09	3.06	4.05	.01	2.95
	Post	3.56	1.12	3.05	4.06		

Qualitative Data. Qualitative data from this study were analyzed contemporaneously using a constant comparative method (Boeije, 2002; Stake, 2010). Using this approach, field notes were transcribed and analyzed using Atlas.ti. With this software, field notes were initially coded. As the contemporaneous analysis progressed, like codes were merged and grouped by category. Categories were then organized by similar themes that emerged. Table 7 presents the themes, categories, and codes that were used during qualitative analysis.

Table 7

Themes, Categories, and Codes Used in Qualitative Analysis

Theme 1: Weak problem-solving strategies		
Categories	*Codes*	
Weak understanding	Misses important information Focused on unimportant info Misapplication of numbers	Misses point of question Overuse of keywords Underlines entire question
Weak planning	Limited planning Utilized ineffective plan	No evidence of planning Could not explain plan
Weak solution attempts	Repeated same action Gave up Impulsive actions	Copies weak peer solution Cannot describe previous steps Solved before understanding
Weak checking of work	Did not check work Did not recognize correct sol. Nonrecognition of progress	Confirmed incorrect answer Answer does not fit context

Table 7 Continued

Theme 2: Strong problem-solving strategies		
Categories	*Codes*	
Strong understanding	Used background knowledge Restated gist of the problem Identified/used important info	Understood problem Eliminated extraneous info
Strong planning	Plans tied to context Described plan	Adjusted plans as needed Tells why plan works
Strong solution attempts	Began at point of misconception Adjusted based on errors Verified	Reviewed info/context Tried wide range of solutions
Strong checking of work	Identified errors Evaluated solution	Labeled work and answer Monitored after each step

Theme 3: Metacognition and Metacognitive Strategies		
Categories	*Codes*	
Evaluative Actions	Reviews process Self-assessment Compares to exemplars	Compares to important info Self-grading Verbalizes self-evaluation
Regulates and Adjusts	References prior work/exp. Changes in actions References previous mistakes	Persists despite frustration Seeks help when truly stuck
Prompts Metacognitive Actions	Metacog prompt: Tchr modeling Metacog prompt: Guiding ques Prompts reconsideration	Models previous know/exp. Models evaluative actions Prompts evaluation
Peer assess/feedback	Peer modeling Peer reinforcement Peer observation Peer grading	Emulates peers – conv Emulates peers – org Adjusts after peer feedback

Table 7 Continued

Theme 4: Teacher Actions and Classroom Organization		
Categories	*Codes*	
Guided Instruction	Guiding Questions Leaves students with next steps Gives concrete next steps	Prompts reconsideration Scaffolding Prompts error identification
Instructional Strategies	Teacher Modeling Use of Exemplars Monitors student understanding	Use of small groups Creates mirrored problem sets
Class Discussions	Provides wait time Models problem-solving skills Use of open-ended questions	Models organization Builds on student responses Reviews actions at conclusion

Merged Data. After the quantitative data and qualitative data were analyzed, they were mixed and integrated to provide a complete description of changes that took place during the study. The mixed data were used to create a table that jointly displays the quantitative results and qualitative findings along with an integrated description of the merged results. Table 8 is the joint display, which is organized by research question and summarizes important findings from the integrated results. The integrated results are discussed in greater detail in the narrative discussion.

Table 8

A Mixed Methods Joint Display Showing the Integration of Quantitative Results and Qualitative Findings

Quantitative Results			Qualitative Findings	Mixed Integration
Research Question # 1 – Student Problem-Solving Practices				
Describe Problem	Pre	Post	- Increased identification and use of important info - Increased planning tied to key information - Increased evidence of strategic use of a range of solution strategies - No change noted in written evidence of planning and verification -Verbal descriptions of problem-solving activities consistently better than written descriptions	Student problem-solving capacity appeared to increase as the study progressed. Strongest increases seen in planning and exploring solutions. Written evidence was limited but strong evidence was found in verbalizations. Student perceptions of success decreased slightly over the course of the study despite increased capability.
Assessment	1.09	1.50		
Survey	--	--		
Explore Solution				
Assessment	1.63	1.89		
Survey	3.27	3.52		
Present Solution				
	1.18	1.53		
	--	--		
Research Question # 2 – Student Use of Metacognitive Strategies				
Identify Information	Pre	Post	- Metacognitive skills difficult to assess - Student reliance on prompting decreased over time. - Students emulated peer/teacher models - Cognitive labs indicate higher levels of metacognitive strategies than written work - Student perception of capacity decreased in several areas	Student use of metacognitive strategies evident in discussion but limited in written work. Students were more independent with strategies that are closely linked to concrete steps. Strong growth in evaluative actions noted in group work as students emulated peers.
Assessment	1.24	1.79		
Survey	3.56	3.72		
Plan/Set Goals				
Assessment	1.56	2.20		
Survey	3.29	3.19		
Evaluation				
Assessment	1.18	1.53		
Survey	3.66	3.63		

Table 8 Continued

Quantitative Results	Qualitative Findings	Mixed Integration
Research Question # 2 – Teacher Perception of Problem-Solving and Metacognition		
	- Third-grade students showed greater growth - Fourth grade students showed limited independent growth, but successful with prompts - Increased organization and clarity - Positive student response to guided instruction strategies	Teacher perceptions of student abilities changes as the study progressed. Teachers felts organization led to stronger problem-solving. The nature of teacher interactions indicated a change in their perceptions of problem-solving ability. The use of prompts decreased as skills increased.

Results of Research

Results for this study are presented within the context of each research question and arranged by themes that emerged throughout the study. Research questions for this study were developed to be relevant at each stage and frame the analysis of emerging data. This question design was selected to emphasize changes in perceptions, skills, and strategies as the study progressed. In some cases, the most valuable insights came early in the study and framed the way that a particular theme or concept was viewed. Therefore, the results for each theme was presented chronologically in a narrative framework beginning with the initial understanding and ending with a description of the answers that emerged from the data.

Results Pertaining to Research Question 1

Research Question 1: What strategies or techniques predominate student practices when solving complex problems?

Understanding the Problem. Identifying important information was noted as a deficit during the problem-framing stage of this project. Thus, several of the initial lessons of the problem-solving intervention were centered on identifying and understanding important information within the context of the problem. During early observations, I noted numerous times that teachers emphasized strategies for identifying and understanding key information. Mrs. Thompson modeled this at the beginning of one lesson where students had to determine how many high-fives would take place on a team, explaining “We know that we need to think about this like a real person on that team would. Let’s start by looking at the information that would be helpful to a teammate”. Minutes later she guided another group by posing the question “If I were trying to figure this out, I would look for information that is majorly important, and then I would think about stuff that is sort of important. What do you think is majorly important?” She followed up with “I know that both of you play ball. Is there anything that the problem doesn’t say, but we know about high fiving players on your team that might help us to solve the problem?”

Initially, many groups relied on guidance from the teacher to make sense of information in the problems. An early interaction with Jackson provided a good idea of this structured guidance:

Mrs. Williams: How is your group doing?

Jackson: We're finished. See.

Mrs. Williams: I see, but I can't tell from your work that you understood what to do in this case. Let's look at the problem together. [Mrs. Williams reads the problem aloud] What do we need to know to solve this problem?

Jackson: How many feet long is the length.

Mrs. Williams: Good, it's right there, but we can circle it since it is important. What else do we need to know?

Jackson: The…..I'm not sure.

Mrs. Williams: Well, we need to find the perimeter, what do we do to find the perimeter?

Jackson: We add the sides. No, we….yeah, we add the sides.

Mrs. Williams: Good, so what else do we need to be able to do that?

Jackson: We need the width too.

Mrs. Williams: Good, do we have the width? I think we have enough information right here. I'll be back in a bit.

On the problem-solving assessment, the mean score related to understanding problems showed slight changes over the course of the intervention. On the pre-assessment, both third and fourth-grade students had a mean score of 1.24. This mean score increased to 1.88 on the third grade post-assessment and 1.71 on the fourth grade post-assessment. Student survey scores, which used a scale of 1 (never) to 5 (always), related to identifying information and understanding a problem showed a small increase between the pre- and post-intervention survey administrations. Among third-grade students, the pre-intervention composite mean was 3.18 (CI_{95} = [2.59, 3.72]; SD = 1.26) and the post-intervention mean was 3.47 (CI_{95} = [3.00, 3,94]; SD = 1.05). A chi-square test showed no statistically significant relationship between scores, χ^2 (4, N = 19) =

4.64, p > .05. A small effect size, *d* = 0.27, was noted. Among fourth-grade students, the pre-intervention composite mean was 3.58 (CI_{95} = [3.23, 3.92]; *SD* = 0.77) and the post-intervention mean was 4.00 (CI_{95} = [3.69, 4.31]; *SD* = 0.69). A chi-square test showed no statistically significant relationship, χ^2 (4, N = 18) = 7.66, p > .05. However, a moderate effect size, *d* = 0.57, was noted. Figure 3 shows the mean composite student survey ratings with 95% confidence intervals pertaining to planning.

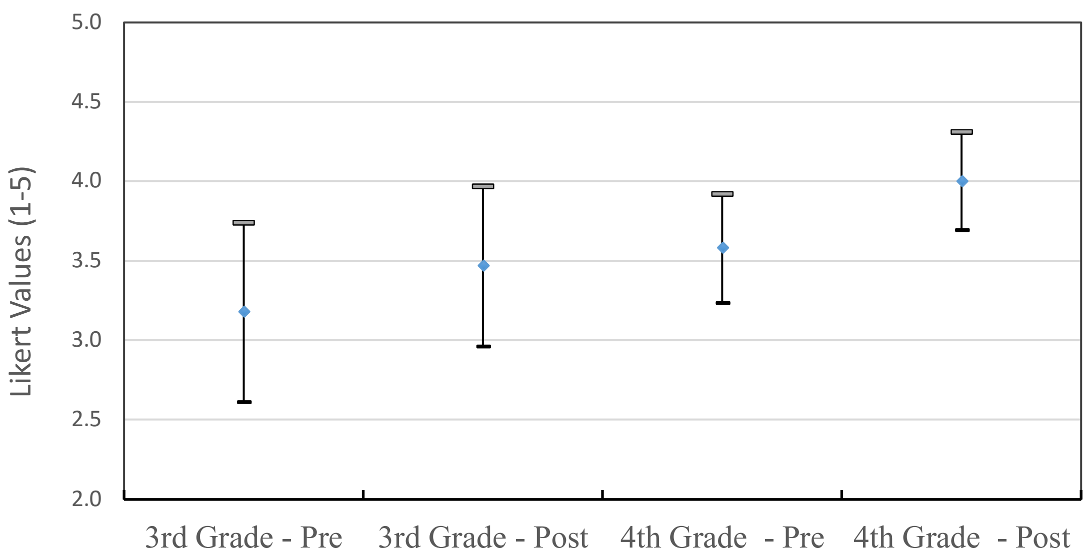


Figure 3. Student survey composite results pertaining to understanding the problem.

Using scaffolding and modeling in guided instruction, teachers were able to provide less support as the study progressed. Towards the end of the study, students would often begin interactions by stating their understanding of the problem and posing questions about specific areas of uncertainty. During a lesson on multi-step problems, Cole asked two direct questions in quick succession:

Cole: I know that I need to divide the flour because she is baking a lot of cakes, but I don't understand what to do with the cost of the cakes?

Teacher: Imagine you were baking the cakes, why would you need to know the cost of the cakes?

Cole: So, I know how much she makes. So first I have to figure out how many cakes there are and then I can get how much money?

At times a marked difference was noted in the written and oral evidence of understanding. In written work, a student's level of understanding often had to be inferred from what they did with the information they used. When specifically prompted, many students were able to write which information was important or explain how a specific piece of information fit into the problem. Those who were unable to explain why the information was important were typically unable to solve the problem. When students were confused, the teacher used scaffolded supports to lead them to understand how information was relevant in that particular context. Once students understood the information, they were often successful in solving the problem.

Planning. Poor planning was identified as a concern during the problem framing stage of the study. The pre-intervention quantitative data showed a similar weakness in planning. On the problem-solving pre-assessment, the mean score was 1.59 for third-grade students and 1.53 for fourth-grade students. Student scores on the problem-solving post-assessment showed a larger improvement among third grade students with a mean score of 2.47 and modest improvement among fourth grade students with a mean score of 1.94. Among third-grade students, the pre-intervention composite mean was 3.42 (CI_{95} = [2.92, 3.91]; SD = 1.10) and the post-intervention mean was 3.30 (CI_{95} = [2.82, 3.78]; SD = 1.07). A chi-square test showed no statistically significant relationship, χ^2 (4, N = 19) = 3.65, p > .05. A small effect size, *d* = .10, was noted. Among fourth-grade students, the pre-intervention composite mean was 3.16 (CI_{95} = [2.63, 3.69]; *SD* = 1.18) and the post-intervention mean was 3.08 (CI_{95} = [2.55, 3.61]; *SD* = 1.18). A chi-square test showed no statistically significant relationship, χ^2 (4, N = 18) = 1.60, p > .05. A very small effect size, *d* = 0.06, was noted. Figure 4 shows the mean composite student survey ratings with 95% confidence intervals pertaining to planning.

As noted previously, student perceptions of their performance were lower than the perceptions of their teachers as well as lower than scores on the problem-solving assessment. A decrease in our students' perception of their ability to plan was noted in the student survey results. It is possible that this decrease, while unexpected, is related to an increase in calibration between student perception and actual ability and corresponds with observations from intervention lessons in which students struggled with developing a quality plan. Statements such as "making a good plan is so much harder than I thought" and "I used to think I was way better at making plans" were common during observations as student struggled with challenging tasks. Thus, the decrease in student perception may have occurred because previously overconfident students gained a more realistic view of their ability.

During observations, weakness in planning was most notable in the haphazard use of strategies. Rather than implementing plans based on the information and context of the problem, many students computed simple calculations with all of the numbers in the problem.

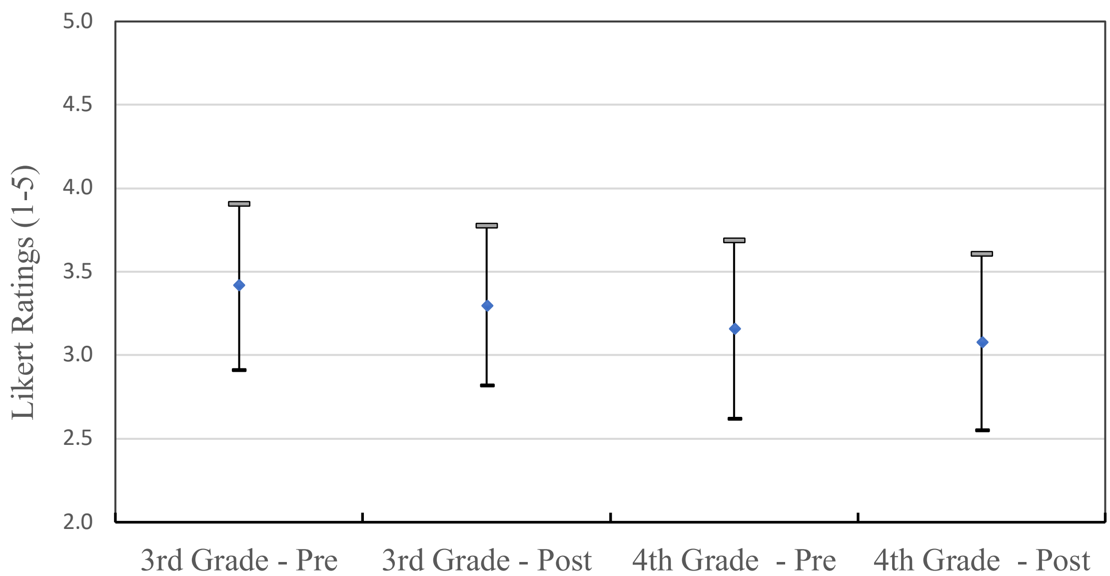


Figure 4. Student survey composite results pertaining to planning for problem-solving.

Over time, students began to exhibit an increased use of planning that was tied to relevant information. While working on a problem involving a mission to Mars, Angie discussed her plan with me before solving it with her group:

> We are supposed to get from there [the place their ship landed] to the colony. It says that we are 20 miles away, so we need to worry about breathing air and water and knowing where to go. So, we are going to pick out what we need in order to breathe and drink and a map. Like, we have to get the oxygen tanks to survive, and we have to get the bottles of water. Then we'll decide if the other things are important.

During a following classroom observation, the teacher prompted students to write out their plans before they solved the problem. Russell, who often struggled with word problems wrote "I will divide 28 by 3 because the baker is cooking three cakes and what it takes for 28 cakes. I don't multiply because the number would be too big."

It is important to note that there was little change in the written evidence of strategic planning. Students were able to describe their plan accurately when specifically directed, but seldom included descriptions of plans in their written work. Planning could often be inferred from a close examination of the solution attempts, and there appeared to be little difference in the rates of success among students who wrote out plans of their own initiative and those who did not. Mrs. Thompson noted an increased success rate of students who were able to write out strategic plans when directed, stating "if I remind them that they need to write their plan out, most of them look great and their answers are correct. But there are some kids who can't, and they write something down for a plan, but I don't know that it helps." Mrs. Williams added that "usually the students who take the time to write out their plans are the ones who don't need to."

Exploration and Solution. At the beginning of the study, students would often arrive at an answer that was incorrect and merely repeat the same steps with little or no adjustment. Multiple times during problem-solving lessons and classroom observations students repeated the same incorrect steps three or more times with no real idea of how to adjust their work. Teacher modeling and guiding questions were especially effective at encouraging students to try solution attempts that would eventually be successful. As students became more adept, teachers were able to provide less active support, opting for open-ended questions that prompted a change in thinking.

Quantitative data related to this aspect of problem-solving showed notable growth. Students in the third grade had a mean score of 1.59 on the "explores solutions" domain of the problem-solving pre-assessment. This score increased to 2.53 on the post-assessment. The mean score for fourth grade students increased from 1.65 to 2.24. Among third-grade students, the pre-intervention composite mean was 3.22 (CI_{95} = [2.68, 3.75]; *SD* = 1.18) and the post-intervention mean was 3.56 (CI_{95} = [3.06, 4.05]; *SD* = 1.10). A chi-square test showed no statistically significant relationship, χ^2 (4, N = 19) = 9.45, p > .05. A small effect size, *d* = 0.29, was noted. Among fourth-grade students, the pre-intervention composite mean was 3.29 (CI_{95} = [2.77, 3.81]; *SD* = 1.16) and the post-intervention mean was 3.48 (CI_{95} = [3.02, 3.94]; *SD* = 1.02). A chi-square test showed no statistically significant relationship, χ^2 (4, N = 18) = 3.08, p > .05. A small effect size, *d* = 0.17, was noted. Figure 5 shows the mean composite student survey ratings with 95% confidence intervals pertaining to solving problems.

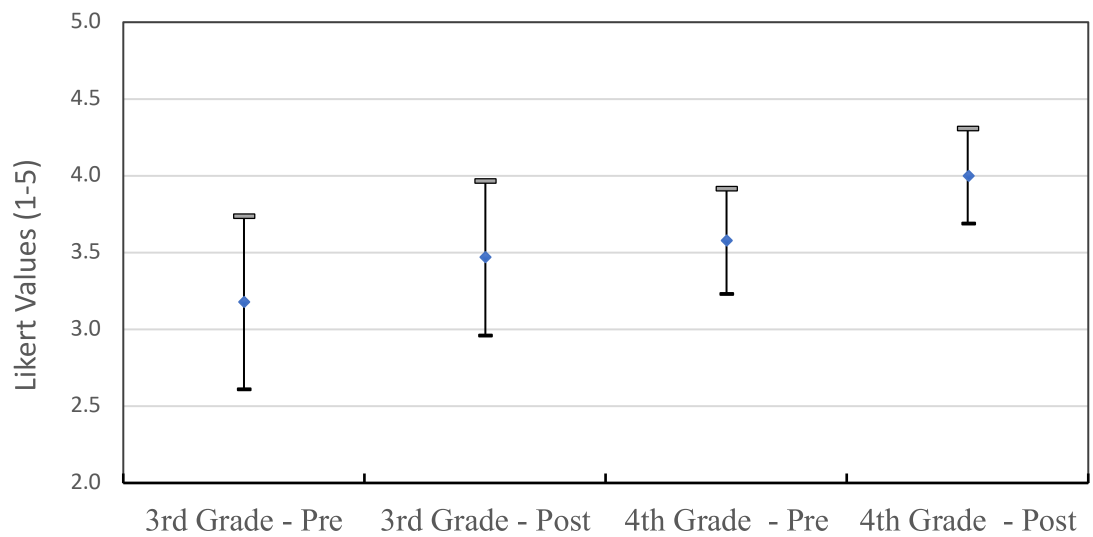


Figure 5. Student survey composite results pertaining to solving problems.

As the intervention progressed, proficient problem-solvers were consistently able to change course as they ruled out faulty approaches or gained new information. Students who struggled to explore and adjust solutions were often unsuccessful at an earlier stage of problem-solving. While solving a problem in which students were asked to arrange playing cards so that they could be dealt in a specific order, Samantha made several mid-course corrections. Figure 6 shows Samantha's work along with a summary of her discussion with her teacher.

Problem

Jason and Troy are practicing card tricks after school. Jason shows Troy a trick where he deals the cards Ace through 10 in order. The trick is how you deal them out. Jason takes the first card, an Ace, and lays it down on the table. He puts the second card at the bottom of the stack. The third card, a 2, goes on the table, and the next card goes to the bottom of the stack. He does this until all cards have been placed on the table in order. How did Jason do the card trick?

Samantha's solution	*Samantha's discussion with her teacher*
[Samantha made several incorrect solution attempts. Each attempt was erased and is illegible]	[Samantha is using cards she created out of notebook paper to act out the card trick]
	Samantha: It's impossible; everything's wrong.
	Teacher: Show me what you have tried so far.
	Samantha: Ummm [she cannot remember her steps and cannot read the erased work]
	Teacher: Let's write each try down so you don't keep trying the same thing over and over again.
A 2 3 4 5 _ _ _ _ _	*Samantha:* This can't work because I have to put the cards down between each.
A 6 2 7 3 8 4 9 5 10	[Samantha begins to use a trial and error to adjust her next solution attempt by replacing the incorrect card with the card she wants to appear.]
A 6 2 7 3 8 4 10 5 8	*Teacher*: Great! Keep it up.
	[Samantha continues to act out the card trick and quickly finds the answer then raises her hand]
A 6 2 8 3 10 4 7 5 9	*Teacher*: Did you get it?
	Samantha: It was easy once I knew what to do.
A 6 2 10 3 7 4 9 5 8 Answer	*Teacher:* How did you solve it?
	Samantha: I just put the right card where it should go when I was stuck and did it again.

Figure 6. Samantha's work sample and a description of the interaction with her teacher.

Additionally, stamina and determination played a role in the students' ability to stick with challenging problems. An increase in the organization of solution attempts was noted during the sixth week of the intervention while students were working on various logic-type problems. Sarah and Cammy's group, which was unable to solve problems in two previous observations without direct teacher assistance, was able to demonstrate persistence in adjusting their solution. In one particular scenario, the students had to figure out how to balance items on a raft in order to keep it from sinking. Each item had a different weight, which had to be arranged in a specific order so that each row and column was balanced. Their interaction was a good example of this persistence:

> *Sarah*: We can't place the water in the middle since it will make each of our answers too heavy.
>
> *Cammy*: We can try the clothes, it doesn't weigh much.
>
> *Cammy*: Never mind, that won't work the rows don't go enough.
>
> *Sarah*: Okay, maybe it's we can try this one. (they send 5 minutes trying multiple objects in the center)
>
> *Teacher*: It looks like you have done quite a bit of work, what are you doing now?
>
> *Sarah*: We have to use this one because it's not too big or small.
>
> *Cammy*: We found a way to make it by putting the lightest one with the heaviest one. We thought it was right, but the ends were wrong. We need to switch something. (teacher leaves and students quickly get the correct solution).

Verification of Solutions. Initially, students demonstrated very little evidence of evaluating the accuracy of their solutions. During classroom observations and cognitive labs, where evaluative thinking is more apparent, student use of evaluation was often cursory and superficial. In several cases I watched students realize something might be incorrect but continue with their current or original strategy, or just leave an answer that they felt was incorrect. When asked about this, they often responded that they did not know what to do or did not know if it was correct.

Much of the work that students initially engaged with followed a multiple-choice format and students were highly dependent on available multiple-choice answers to determine whether their work was correct. Celeste used this type of evaluative thinking when she incorrectly assumed her answer was correct during an early cognitive lab, stating:

> I know that I have to add the sides together so that I can find the area. I need to write nine at the top for the length since they only put it at the bottom. They try to trick you, by only putting one down. Then I need to write four for the width because it's only on one side. Then I add them all up to get the area. So…..I wrote them down. Nine plus nine is…..eighteen, and four plus four is….8. Then eighteen plus eight is twenty-six. It's right there, so it is my choice.

When students did not have multiple choice answers to assist in verifying their answers, they would typically draw a box around the last calculation they made. When prompted, they were often unable to explain why they thought their answer was correct. Those who did explain why they thought their answers were correct would usually just repeat the steps as noted in this interaction:

> *Teacher*: How can you tell that your answer is correct?
>
> *Jackson*: Oh..[begins to erase answer]

Teacher: I didn't say it was wrong, I was just wondering how you know it is right?

Jackson: It said that she had six boxes of fruit and six times nine is fifty-four.

Teacher: So, how do you know it is correct?

Jackson: I multiplied.

Student use of evaluation strategies seemed to increase as we focused on them in the intervention and during guided instruction interactions. Students were increasingly able to link their explanations of their answers back to the context presented in the problem. Especially in group discussions, students were able to generate explanations that showed evidence of context-specific evaluation. Ben and Alicia demonstrated this during a classroom observation:

Teacher: Can you explain your answer to me?

Ben: It says that she bought a sandwich and chips, so you have to plus $3.00 and $1.00 because when you buy stuff, you add it together.

Teacher: Okay.

Ben: Then you minus $4.00 from $5.00 since he has to pay, so we got our answer.

Teacher: I see, why did you need to subtract? Alicia, what do you think?

Alicia: When you pay for food you give them your money and get back change. His lunch cost $4.00, so the change is $1.00 since he had a five-dollar bill.

As the intervention continued, there was increasing evidence that students were monitoring the correctness of their solutions as they worked rather than waiting until their work was finished. In group discussions and cognitive labs, there were multiple instances of students identifying an error and going back to the information to see where they might have misunderstood. Once the students corrected their error, they would move on to the next step of the problem. In these instances, the students' explanations of their evaluations often followed the steps they took. RJ showed this type of thinking in explaining the answer to a problem that required the conversion of units of measure:

> At first, I divided the quarts he had by two and ended up with six. I started to go on but realized that my answer would be less than I started with even though he was making enough for a whole class. So, I multiplied, since I was going down to pints and the answer made more sense. Then I knew it was right because twelve quarts would make enough for a whole class because that is… [references conversion chart] three gallons, which is a lot.

Although there was observational evidence of increased verification of answers, there remained little written evidence. When prompted, students were increasingly able to write contextually accurate explanations, but no increase was noted when teacher prompts were absent. Both teachers stated that their students would typically only provide written explanations when specifically asked. They did note an increase in student use of strategies to verify the accuracy of their calculations such as using the opposite operations or working backward through the problem.

Among third-grade students, the pre-intervention composite mean was 3.72 (CI_{95} = [3.18, 4.35]; SD = 1.29) and the post-intervention mean was 3.71 (CI_{95} = [3.13, 4.30]; SD = 1.30). A chi-square test showed no statistically significant relationship, χ^2 (4, N = 19) = 1.16, p > .05. A very small effect size, d = 0.04, was noted. Among fourth-grade students, the pre-intervention composite mean was 3.55 (CI_{95} = [3.06, 4.05]; SD = 1.09) and the post-intervention mean was 3.56 (CI_{95} = [3.05, 4.06]; SD = 1.12). A chi-square test showed no statistically significant relationship, χ^2 (4, N = 18) =

2.95, p > .05. A very small effect size, *d* = 0.01, was noted. Figure 7 shows the mean composite student survey ratings with 95% confidence intervals pertaining to planning.

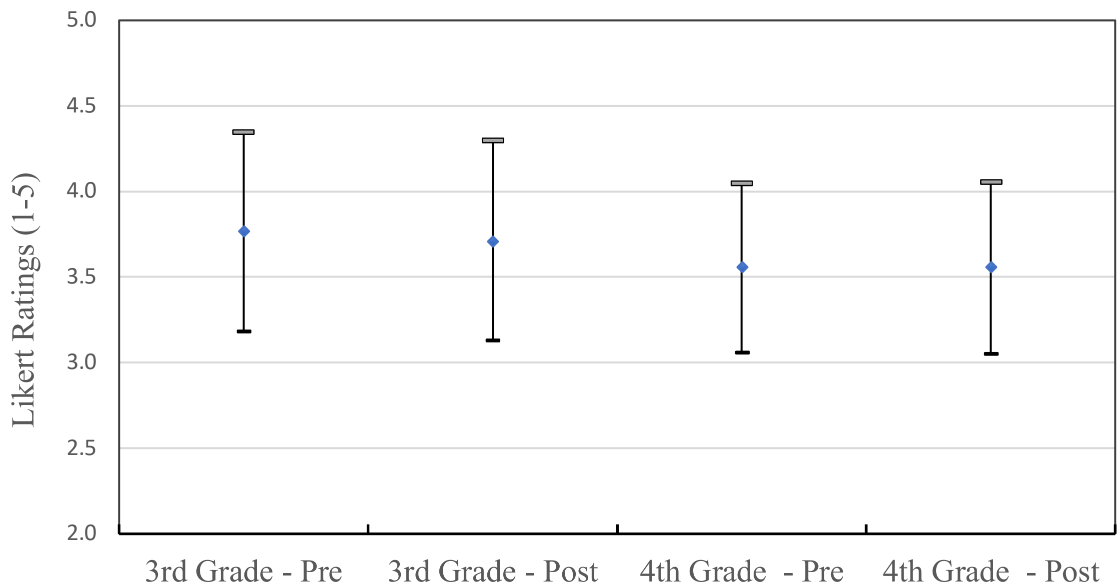


Figure 7. Student survey composite results pertaining to evaluating solutions.

Results Pertaining to Research Question 2

Research Question 2: How are metacognitive strategies used by students who engage in solving complex mathematics problems?

Metacognitive Knowledge and Experience. In this study, the use of metacognitive knowledge and experience was examined in two ways. First, we looked for instances where students utilized background knowledge and experience that was specific to the academic elements of the task. Second, we looked for instances where students used procedural experience and knowledge to approach a similar task. In discussions with students, we reinforced both the use of background knowledge and the utilization of procedural experience.

Initially, students were sporadic in their use of background and procedural knowledge. Students often used background information that was ill-suited to the problem context or ignored important information that did not correlate with their experience. In one instance, Brandon relied heavily on his experience with buying candy at a grocery store. His group was tasked with determining how many snacks a student could buy from a concession stand. The members of his group arrived at the correct answer but were finally persuaded by Brandon's continual insistence that they would not have enough money due to taxes. Eventually, Mrs. Thompson intervened in the discussion explaining that taxes were not mentioned. As the students worked on the next part of the question, Brandon again led them away from the correct answer with a focus on taxes.

At times, students also overgeneralized the use of their procedural experience. This weakness was often due to an emphasis on keywords in problems that mirrored the STAAR. Students were previously taught to look for words such as *altogether*, *more than*, *groups of*, and *total* to determine which operation should be used. Several student errors were observed in problems that contained a keyword that was not used in the expected context. In one multi-step problem, students incorrectly used addition instead of subtraction to solve a problem that asked for the "number of students that will go on the field trip altogether." When discussing their mistake, each student with the incorrect answer stated that they used addition after reading the word keyword altogether.

At other times, students would overgeneralize plans that were covered in class or our problem-solving interventions. In one early lesson, students successfully acted out a problem to find the number of high-fives it would take for each basketball teammate to give each other a high-five. During the next two lessons, several groups quickly started acting out problems that were better solved with other methods.

As the intervention progressed, student use of background knowledge and experience was noted more extensively in classroom observations, group discussion, and cognitive labs. However, little evidence of this type of thinking was noted in written work unless prompted. The contrast in the written and oral record is shown in Figure 8, which is the work of Phillip, a fourth-grade student, who later explained his work during one of the final observations.

Problem

Stacy buys 3 CDs in a set for $29.75. She saved $6.25 by buying the set instead of buying the CDs separately. If each CD cost the same amount, how much does each of the 3 CDs cost when purchased separately?

Phillip's Solution	*Phillip's Explanation*
3 CDs = $29.75 ~~29.75 – 6.25 = 23.50~~ 29.75 + 6.25 = 36.00 $3\overline{)36}$ = 12 $12	*Responding to a question from his teacher about his work on the problem.* "This problem was like the one that we had about the person buying clothes. Since he bought more CDs, it was cheaper. So, I went ahead and added the extra price back." *Teacher asks why he added.* "I added since it would be more expensive, like when you buy Dr. Pepper at the gas station. If you get two, you pay more than one drink, but each one is cheaper. I knew that I had to add the extra money since it would cost more. Plus, I subtracted and got $23.50 and don't know how to divide that number." *Teacher asks about any other ideas he had.* "It also makes sense because each CD costs $l2 if you get them, but it is cheaper if you buy a bunch.

Figure 8. Phillip's work sample and verbal explanation of thinking.

To guide its use, teachers continually modeled discussions that emphasized background knowledge during intervention lessons. Student descriptions of their background knowledge and procedural experience were more prevalent during the last month of the study as students incorporated examples from the teacher into their group discussions. Given the marked increase, it is likely that teacher modeling brought out abilities that the students already possessed rather than developing new skills.

Goal Setting. Due to the young age of the participants and constraints stemming from the brief intervention period, a decision was made to limit the focus on goal setting to smaller short-term goals. All goal-setting activities took place within the context of problems that could be solved within the 45-minute intervention period. Each week, the broader goal was explicitly stated within the problem. Thus, the goal-setting process was framed within the context of choosing smaller steps to solve a problem.

At the outset, participating students varied widely in their ability to determine these smaller steps. The use of guided instruction strategies allowed teachers to provide students in each group with targeted support, which often included guiding questions that helped develop problem-specific goals. Since the majority of student work during this study took place in a group setting, the more proficient goal-setters typically took the lead in planning the steps to solve problems. For two weeks in the middle of the intervention, the student groups were adjusted to place dominant peers into the same groups. In most of the groups, which were now made up of more passive participants, the student who seemed to feel most confident led the process of determining the steps to solve the problem.

As noted earlier, students appeared to show an increase in their ability to understand the context and important information in a problem. Along with this increase in understanding came an increase their ability to determine steps that would lead to a successful answer. There is no evidence though to support an increase in true goal-setting ability during the intervention. However, an increase was noted in the ability of more proficient goal-setters to describe the steps they would take to solve the problem. Observational data from the last three weeks of the intervention also show a reduction in reliance on teacher assistance in developing plans for more routine problems.

Action Strategies/Monitoring. An increase in student self-monitoring was evident in observations of group discussions and cognitive labs. During initial observations, it was not uncommon for students to seek feedback from the teacher at the end of each small step in solving a problem. Often, the students had taken the correct action but appeared to lack the confidence to move on. The following conversation involving Allison and Jeremy was similar to many others that were initially observed:

Allison: I think that we have to multiply first…or maybe add.

Jeremy: I think we have to multiply since each kid ran five laps.

Allison: I think so, I guess [raises hand]

Teacher: How is everything looking?

Allison: We multiplied four times five because each kid ran five laps

Teacher: Okay.

Allison: Is that right?

Teacher: Why did you multiply? [looks at Jeremy]

Jeremy: Each kid ran five laps, and there were four kids, so they all did twenty laps.

Teacher: Do you agree?

Allison: That's what I did.

Teacher: It looks like you knew what to do all along.

These types of ongoing requests for teacher feedback stood out early on during the ongoing qualitative analysis. As a result, we began to emphasize ways to monitor thinking in the intervention lessons. Rather than engaging with students immediately, we would prompt them to continue thinking about their work to see if they could tell if they were on the right track. When we did provide this confirmatory feedback to students, we would do a think aloud with them to model how we knew the step was right or wrong.

A decrease in student requests for confirmation was noted in classroom observations during the last half of the study. Instead, students seemed to more independent in monitoring the success of their work. Several times, I observed students using the same language and advice that had been modeled by the teacher. In a cognitive lab during that took place five weeks into the intervention, Phillip, who often struggled to explain his thinking, stated:

> Next, I am going to divide because there are 72 muffins, but they have to be shared in four classes. So, I get….18 muffins. That seems right because that is about how many kids are in a class. I know that I was right to multiply first to get the total muffins, then I was right to divide, so I have enough for each class.

In addition to a decrease in requests for confirmation, teachers noted an increase in context-specific requests for information. Mrs. Williams stated "[my students] are asking questions that are more specific. I've noticed them talking things through before checking with me." Mrs. Thompson added "a lot of times I'll check in with a group, and they'll give an update but have fewer questions. I think they ask less questions because we've spent so much time telling them that their questions 'seem like something you can figure out on your own'".

Evaluation. Our students' limited ability to evaluate their work was a significant concern that emerged during the problem-framing process. Teachers and parents felt that many students had a confidence level that was poorly calibrated to their ability and the quality of their work. This mismatch in self-perception was frequently noted during observations and cognitive labs during the first six weeks of the intervention. In some cases, students lacked confidence as they underestimated both their own skill level and the accuracy of their solutions. In others, students were overconfident and had a high degree of certainty that their work was correct.

During the first few classroom observations, it was not uncommon for students with incorrect solutions to justify their thinking by simply restating the steps they took to solve the problem. These limited descriptions typically lacked context and were rooted more in assessing the accuracy of calculations rather than the appropriateness of the solution. Jackie used this approach in a class discussion when explaining how she knew her answer was correct, stating, "I subtracted nine and four and got five. Then I did five plus five plus five and my answer is fifteen." When asked by the teacher how she knew that fifteen was the correct answer, Jackie replied "After I subtracted and added I got fifteen. Then I made sure my work was right."

Teacher modeling and the use of probing questions during independent work time seemed to be effective in prompting students to use reflective thinking in the evaluation process. It often only took a brief interaction with the teacher for students to evaluate their own work and realize that their solution was inaccurate. The participating teachers became especially skillful at bypassing these more simplistic descriptions by asking context-based questions that changed the way a student thought about the correctness of their answer. During one classroom observation, Mrs. Thompson met briefly with Harmony after watching her solve a problem incorrectly.

> *Mrs. Thompson:* Harmony, it looks like your answer is different than everyone else at your group. How well do you think your solution answers the question?
>
> *Harmony:* I added fifteen and fifteen. Then I divided it by three. So, my answer is ten.
>
> *Teacher:* So, how do you know that the answer is correct?
>
> *Harmony:* Because that what I got when I did all the steps.
>
> *Teacher:* I can see that, but you still haven't really told me how you know your answer is correct. When I look at your work, I see that you added and multiplied correctly. Sometimes though it helps to think about what the person in the problem is doing.
>
> *Harmony:* They're exercising each day.
>
> *Mrs. Thompson:* Right, so what do they do each day?
>
> *Harmony:* They run for fifteen minutes and then practice their routine for fifteen minutes. Oh! It can't be ten, because that is way too small. I should have multiplied by three.
>
> *Mrs. Thompson:* Good, that's part of it. Keep working! And make sure that it makes sense for the person in the problem.

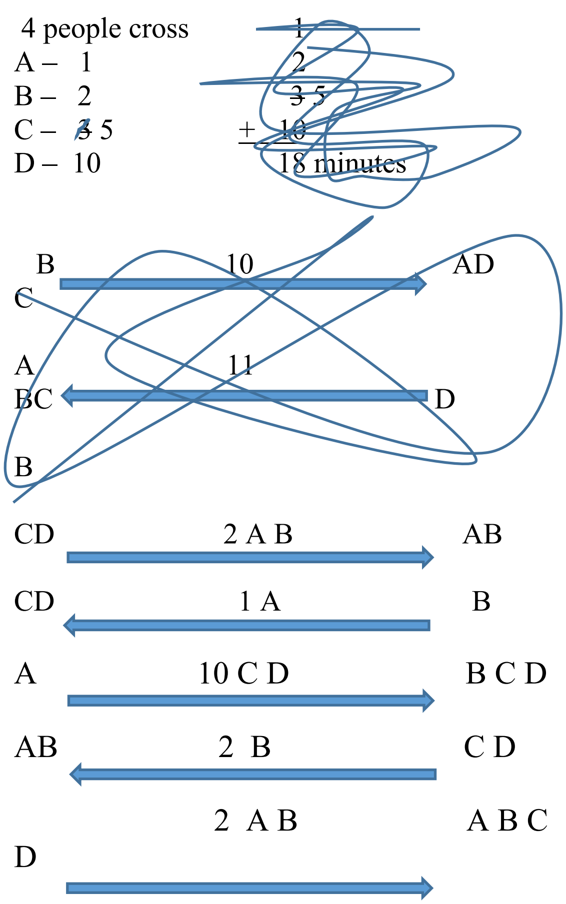
With the ongoing focus on prompting context specific evaluations, an increase in evaluative statements was noted in observations of group work and during cognitive labs. While students often had to be prompted to provide their evaluative thoughts, their descriptions tended to be more contextually accurate and less a restatement of the steps they took. Figure 9, which is a good example of this change, shows Harmony's written work on a complex problem along with her verbal response describing why she felt her answer was correct.

Indirect evidence also pointed to an increase in self-evaluation. Mrs. Thompson noted a significant decrease in incorrect answers and an increase in independent changes to incorrect student work. When asked to describe these changes she replied "Their work on word problems is a lot better. I've noticed an improvement in organization, but it also seems like they are catching more of their mistakes before they turn in their work. I've noticed more assignments where work has been erased and fixed. Even [two students who often rush through work] are catching more of their mistakes."

Problem

A bridge will collapse in 17 minutes.
4 people want to cross it before it will collapse. It is a dark night and there is only one flashlight between them.
Only two people can cross at a time.
"A" takes a minute to cross. "B" takes 2 minutes.
"C" takes 5 and "D" takes 10 minutes.
How do they all cross before the bridge collapses?

Harmony's Work Sample



Harmony's Explanation

"At first, I started off without a plan. I just added the minutes up for each person and got 18. So, I said the answer was no. Then I realized that it said that two people could cross at a time. So I then thought that they could do it in 9 minutes since 18 divided by 2 is 9. But I knew that was wrong because the slow kid took ten minutes. Then I started to act it out."

"I had the two slowest people go together, but it took 15 minutes for C to get back with the flashlight, so I knew it wasn't right. Then I made little slips of paper with each person on them and acted it out. So, my mistake was like, I had one of the slow people coming back with the flashlight, so it was impossible. After acting it out, I found out that if I sent the fast people over, then they could take the light back and forth. The slow kids could go together; that part was right, but a fast kid had to go back with the light."

"I ended up with my answer of 17 minutes, which is right, and they get across in just the time. Oh, I need to write it down, you can tell if you look at my kids going across, but I didn't write the answer down."

Figure 9. Harmony's work sample and verbal explanation of thinking.

A similar change was noted in the quality of student and teacher interactions that took place over the course of the intervention. Initially, students would frequently ask for confirmation that they were on the right track. Before the intervention, teachers would typically either provide confirmation or assistance. As part of the guided instruction strategy that was implemented, teachers began asking guiding questions that were tied to the context. Over the course of the intervention requests for confirmation were noted less frequently and student questions were more likely to be about a specific step in their process.

Results Pertaining to Research Question 3

How do teachers perceive their students use of metacognitive and problem-solving strategies when solving complex problems?

Perception of Student Success.

Teacher perceptions of changes in their students' problem-solving ability were mixed. In general, both participating teachers felt that their students were more proficient problem-solvers after participating in the problem-solving intervention. They noticed an increase in their students' performance on harder problems and in the quality of group and class discussions. Additionally, they felt that their students were more organized in their thinking and had greater confidence in their work.

Both teachers described changes in both the group dynamics and class discussions. Mrs. Thompson described a recent group discussion, stating:

> They were talking about the parts of the problem that were pretty difficult. At the time they had a hard time coming up with a plan that would work. They

> knew that their answer was wrong, but they weren't sure what it should be. As a group, they began to go back to the important information and described why each number they used was necessary. As they talked, they realized that a specific sentence had information that they didn't need to solve the problem. So, I see a big difference in the way they approach problems together.

Mrs. Williams also noticed a difference in classroom interactions and emphasized a change in student discussions:

> I've been impressed with the changes I have seen in some of the quieter students. They're starting to sound more confident in their descriptions of the work they are doing. I think they have always been better than we thought, but have lacked confidence, or were willing to sit back and let other kids do the work for them. I've been impressed with kids like Sally who have stepped up and will voice their opinions.

She provided a specific example from the day before:

> Usually the kids in Sally's group would do the work without her and eventually, she would just copy down the things they did. At first, I noticed that she would have different work than the rest of the group and seemed to be working through things independent of the group. As we have gone on though I've noticed that she is more engaged in the group. Yesterday she had the correct answer and the rest of the group had taken the wrong approach. As I watched, she explained why her work was right and described each step she took and how it matched the problem. They realized their error and changed the work. After that, she kind of took the lead for the day.

Both teachers also described a change in the calibration of their student metacognitive thoughts. Mrs. Thompson described a change in the confidence level of her students. Speaking about students who always needed reassurance in their work, she explained, "I always felt like they were asking questions that they knew the answer to but were too worried about making a mistake. Lately though, I've noticed less of that and more or them just working." Mrs. Williams echoed this sentiment and added that she has also noticed that:

> Some of them were overconfident and always thought that their work was great. They would make a lot of silly mistakes because they rushed or did not take the time to really understand a problem. We review their work in class and it never seemed to bother them. Recently, they've watched other students improve and pass them in ability. I know that it has been really frustrating for them, but I think that it has been good for them to see other students buckle down and do so well. They seem more likely to put in extra effort to make sure their work is right, especially if they have to talk about it in class.

Perception of the Quality of Student Work. Our third-grade teacher noted that the quality of her students' work improved dramatically during the intervention period. After only two weeks she stated, "you'll be amazed when you see their test from last week. Their grades went up, but the work that they showed and the effort they put into it was completely different." She continued, noting "I think that they had it in them all this time, but it hasn't come through until now."

She also believed that her students were much more successful when solving problems because of the organizational structure that the lessons provided. She explained that several of her students "work hard to show their steps in a way that makes sense. It is much easier to tell what they are trying to do, and they make sure to label their work so that others could understand it." Despite an increase in overall quality, she notes that there is very little change in the evidence of metacognitive thought in their written work. She explains:

> I don't think that they will ever get to the point where they write out their plans or really explain why their answers are correct. They will write it down if I make them, but not on their own. Most of the time I can tell that they have a good plan from the work that they are doing, and I can tell that they are assessing their answers when I ask them to describe them. I think that that is what is important though. It doesn't really matter if they write it down as long as they are making good plans and then know why their answer is right or wrong.

In fourth grade, the teacher described an increase in the quality of work when students were specifically prompted to use the problem-solving and metacognitive strategies we practiced but stated that "there isn't a lot of difference in the work that they are doing now." She continues:

> If I remind them or tell them that I will be looking for specific things, like writing down important information or explaining how you know your solution is correct, then they will write it out. A lot of times I can look at their work and then give them a look, like 'it's missing something' and they'll say 'oh, I still need to prove my answer.' I know that they are better at doing these things, and it seems like they do them on their own more often, it's just hard to tell unless you ask them.

She adds that one aspect that has improved is in their ability to assess the work of peers. She stated that "they know the things to look for when they go over a partner's work. They will ask each other questions like, 'how did you get your answer?' and 'what information did you think was important?'. They will also point out where their partner's work is disorganized or hard to understand.

Interaction Between the Research and the Context

Impact of Context on Research. The campus context had a significant impact on this study. The study was tailored to meet specific needs on our campus and designed to fit as seamlessly as possible into the regular schedule and curriculum. The research questions were written to provide information that will be used to improve mathematics instruction at the campus level. Intervention lessons were developed to support goals identified by participating teachers, and sources of data were purposely selected to yield data that could be useful in the local context.

Three context-based operational issues had a small impact on the study. The first operational issue was that one participating teacher changed grade levels over the summer. The start date of the intervention was pushed back by two months to allow her to get settled and become more familiar with the year-long scope and sequence of the mathematics curriculum. The second operational issue stemmed from a busy fall schedule that made it necessary to reschedule intervention lessons and observations during three of the nine weeks. Twice, we were able to reschedule the missed lessons at a different time during the week. However, we had to extend the intervention for an additional week to accommodate benchmark testing that was scheduled in late November. The third context-based issue was an ongoing flu outbreak that led to an abnormally high rate of student absences over the last five weeks of the intervention period. To alleviate this concern, I scheduled additional time during these weeks to meet with individual students as they returned to school.

Stakeholder reaction to the project was generally positive. Participating teachers were highly engaged in the intervention and have continued to incorporate many of the problem-solving strategies and guided instruction techniques in their classrooms. With a few exceptions, participating students enjoyed the lessons during the problem-solving intervention. Administrators were consistently supportive and were very flexible in allowing me to adjust my daily schedule to complete activities related to the study. There was no stakeholder resistance to this project.

Impact of Research on Context. Results from this research project were shared formally in a summary of findings at the conclusion of the study. Relevant results that emerged as part of the contemporaneous qualitative analysis were shared with participating teachers as the study progressed. After the study, I met with students from each class to discuss areas of growth that were seen in the results.

Reactions to the project were positive, and the results had an impact on mathematics instruction on our campus. Participating teachers maintained a focus on problem-solving after the intervention and have incorporated guided instruction into their mathematics instruction. Findings from the study will be used to make adjustments over the summer. In the coming school year, a focus on problem-solving and metacognition will be extended to fifth and sixth-grade classrooms. The deeper understanding of our students' problem-solving practices and a focus on more complex problem-solving were perceived as useful.

CHAPTER V

CONCLUSIONS

Summary

The purpose of this mixed methods record of study was to explore the effects of a nine-week intervention program teaching problem-solving and metacognitive skills. Quantitative data were collected through the use of pre- and post-intervention student surveys and problem-solving assessments. Qualitative information was collected through classroom observations, semi-structured teacher interviews, and cognitive labs. Quantitative and qualitative results were analyzed separately then mixed after completion of the study for interpretation.

Research questions for this study consisted of:

1) What strategies or techniques predominate student practices when solving complex mathematics problems?
2) How are/were metacognitive strategies used by students who engaged in solving complex mathematics problems?
3) How do teachers perceive their students use of metacognitive and problem-solving strategies when solving complex problems?

Participants in this study consisted of 21 third grade and 20 fourth grade students and two teachers. The problem-solving intervention was conducted from October 2017 to January 2018. Quantitative data were collected pre- and post- intervention and analyzed after collection. Qualitative data collection took place on an ongoing basis and the data were analyzed contemporaneously to help inform our understanding of the problem and the effectiveness of the intervention.

As a result of this study, we found that our intervention was successful in increasing student use of strong problem-solving behaviors. The largest increases were seen in the areas of understanding problems and exploring solutions. During teacher observations and cognitive labs, significant gains in planning and evaluative actions were noted that did not necessarily appear in the written work of students.

Third-grade students appeared to exhibit the greatest improvement in problem-solving ability and the use of metacognitive strategies. Much of this improvement seems to be tied to a significant increase in the organization of the students' written work and was seen within the first four weeks. Thus, it is possible that many of the effects were a product of a focused effort on organization and the structured approach to problem-solving that the intervention provided. As such, it is important to note that it is possible that our third-grade students entered the intervention with strong problem-solving skills that were aided by the intervention's organized approach. Fourth-grade students also appeared to exhibit an increase in problem-solving ability and the use of metacognitive skills. However, these increases were less noticeable and required significantly more prompting on the part of the teacher.

Discussion of Results in Relation to Existing Literature

Though the problem and research questions were selected based on needs identified in the local context, the existing literature on problem-solving (Polya, 1945;

Schoenfeld, 1985) and metacognition (Flavell, 1979; Halpern, 1998; Kramarksi & Mevarech, 2003; Schraw & Moshman, 1995.) played an essential role in the development of this study. In most instances, the results of this study aligned with the concepts and practices identified in the review of previous research. Four key areas of alignment with the research were identified as well as one area where the results diverged.

The first area that aligned with the existing body of research was found in the difficulty that we faced in trying to evaluate the problem-solving and the metacognitive skills of participating students. Assessing these skills was an ongoing challenge that required continual checks for understanding and follow up questioning. The utilization of cognitive labs and the implementation of guided instruction strategies helped this process greatly and provided invaluable insight and understanding. This experience highlights the need for teachers to employ strategies that allow students to adequately describe their thinking process and rationale.

The second area that aligned with existing research was noted in the increased structure of student work. An increase in organization and solution structure was evident during classroom observations and discussed during teacher interviews. Though the change in student work is more likely the result of an increased focus on structured solutions than a growth in their problem-solving ability, it corresponds with changes noted in the literature.

The third area that aligned with the existing body of research was found in an increase in student determination. Findings from the body of research that were supported by the results of this study are the ideas that determination can be developed over time as noted by Duckworth and Yeager (2015), and that as students become more successful, they will work to reduce factors that inhibit success (Gollwitzer, 1999). As the study progressed, the increased determination was noted in multiple ways. Changes in the nature of student and teacher interactions pointed to a decreased reliance on teacher assistance and an increased ability to persist in challenging work. Observations of group interactions pointed to a willingness on the part of students to adjust approaches and continue with challenging tasks. An increased determination was also noted in cognitive labs, where students demonstrated less frustration and greater self-regulation over the course of the intervention. The movement from an instructional model where teachers provided students with continual confirmation to one where students were guided to reflect on the accuracy of their work had a great impact in mathematics classes on our campus. This shift allowed teachers to focus on providing deeper feedback and intervention and allowed students to develop confidence in their problem-solving ability.

The fourth area where the results corresponded to the existing research was in the effectiveness of the guided instruction strategy. In both the intervention lessons and classroom observations, guided instruction techniques were highly effective in prompting student use of effective problem-solving and metacognitive strategies. As noted in the existing research (Carpenter et al., 1996; Fisher & Frey, 2010) this instructional strategy was especially effective in shifting responsibility from teachers to students. One particularly effective aspect of guided instruction was the ability for teachers to briefly model an effective strategy or thought process with students and then allow them the opportunity to immediately practice. This just-in-time intervention was especially useful as teachers became more adept at giving small but impactful advice, questions, or feedback. As the intervention progressed, teachers were able to reduce the frequency and intensity of their small group interactions as students were more successful with less prompting.

The results diverged from the existing literature in the finding of a decrease in student self-efficacy. Schunk (1989) described a link between the ability to implement effective strategies and increased self-efficacy. In this study, students had a lower perception of their problem-solving capacity despite an increase in ability. Perhaps this decrease in student self-efficacy stems from an increase in the calibration of our student's perceptions of their ability. In essence, our students felt like they were weaker problem-solvers as they gained an understanding of what strong problem-solving looks like.

Implications for Practice

The research findings suggest that an instructional emphasis on problem-solving and the use of metacognitive strategies has the potential to develop our students' problem-solving ability. The effects on the overall quality of work were most pronounced with our third-grade students who were just beginning work on problem-solving activities. In our fourth-grade classroom, students had to unlearn more simplistic approaches to problem-solving. These results suggest that a more strategic approach to problem-solving and metacognitive action is beneficial when initiated in third grade as students begin to learn how to solve problems. Further research at the campus level could be undertaken to determine if this approach could be adapted for use at even lower grade levels.

Throughout the study, a marked difference was noted in the evidence of students written descriptions of their thinking and verbal descriptions. A consistent theme that arose during interpretation was that a student's written work was a poor indicator of success in problem-solving. While strong written work consistently aligned with successful problem-solving, weaker written work did not always correspond with a poor attempt. It is possible that the current focus on emphasizing written evidence of planning and evaluation is of limited value. Moving forward, it is important that mathematics teachers develop a problem-solving model that encourages those processes that were often missing from written work (e.g., use of background information, evidence of planning, and evaluative statements). Additionally, this model should allow students to demonstrate these processes in ways that are authentic, streamlined, and useful to students.

The results also suggest that our students respond positively to guided instruction. The scaffolded support and gradual release aspects of this teaching strategy were observed to be especially useful in guiding students through complex material. Perhaps a schoolwide focus on guided instruction will help teachers integrate these student-centered supports into their instruction. The results also demonstrated that teachers responded more positively to guided instruction as they gained experience with its use in their classrooms. Professional development in guided instruction could be more effective if provided gradually in smaller sessions that are paired with classroom-based mentor support.

Limitations

Though this study was designed to meet campus-specific needs, there are limitations that impact a potential broader implementation. The first limitation stems from the small size of the study. In addition to the quantitative limitations that were previously discussed, the qualitative results might have looked much different if the study was conducted in other classrooms. While the results are meaningful in our local context, they would represent a starting point for further development of a schoolwide problem-solving model on another campus. Further research will be helpful in refining the approach to meet the needs of all of our students and classrooms.

The second limitation of this study relates to the willingness of the participants. In this case, participating teachers were excited to take part in the problem-solving intervention and prepared to implement changes. Also, I believe that my previous experience with participating students played a role in their excitement for the intervention and willingness to participate. Those aspects of the study that appear to have been most successful such as guided instruction, the use of complex problems, and a focus on the practical application of metacognitive skills would be difficult to implement in the classroom of an unwilling teacher.

This third limitation relates to its ability to be applied to other campuses. While this study could be easily adapted to be implemented in other elementary schools, the unique size and staff considerations on our campus limit the generalization of the results to other campuses. Several important factors, such as close collegial relationships, low staff turnover, and teacher knowledge of students found on our small campus, played a role in shaping the results and cannot be easily replicated.

The fourth limitation of this study stems from the difficulty in implementing these strategies on a long-term basis. The study took just over two months to complete, which is a relatively short period. However, the successful implementation of these strategies requires additional planning, preparation, and energy. I noted no decline in excitement among participants, but it is essential that a long-term solution be seamless, easy to implement, and viewed as authentic and meaningful. It would take careful planning to implement these findings into the broader curriculum on a permanent basis.

Lessons Learned

This project has had a significant impact on views on teaching mathematics and the value of educational research in the local setting. While I walk away from this project with dozens of insights, three key lessons stand out in their impact. The first lesson is that teachers do a poor job of assessing skills and knowledge that are hard to see. My experiences during classroom observations and cognitive labs showed me how incomplete a teacher's view of student performance is without the ability to understand a student's thinking. Several times I was struck by how much the thinking that a student described added to my understanding of their work. At times, their descriptions led me to realize that work that seemed more or less accurate was way off track. Conversely, there were times when work that seemed chaotic and out of context made perfect sense when the student described their thinking. As a result of this project, I am even more committed to finding ways to truly assess my students' knowledge and understanding.

The second lesson is that it is incredibly difficult to analyze a student's problem-solving ability. While I realized that written work only provided a small picture of their overall understanding, I believed that it provided a more comprehensive look at their ability to solve problems than it actually does. Throughout the study, I was often surprised to see a depth of thought that did not show up in a student's work. During many observations and cognitive labs, student use of problem-solving and metacognitive processes was much more complex and nuanced than was evident in their written solutions. Additionally, there were multiple instances where a student's descriptions of their thinking processes showed weak problem-solving skills despite written work that appeared to be accurate.

Finally, through this project I have developed an appreciation of the importance of localized research. The process of conducting campus-specific research led us to several discoveries that were surprising and at times contradicted our expectations. Especially in smaller schools where educators operate more or less independently, teachers lean heavily on anecdotal evidence and past experience. The planning and structure of campus-based educational research can help stakeholders identify and analyze the effects of strategies and approaches that are implemented in the local context.

Recommendations

Based on the research findings, three recommendations were presented to school stakeholders. First, a campus wide problem-solving model should be developed to guide student problem-solving. The research findings suggested that the most significant changes took place when students are taught within the context of a structured problem-solving model during their initial experiences with problem-solving. Rather than relying on classroom-specific problem-solving strategies that change as students move to higher grades, a campus wide model would provide students with clear expectations and a structure for effective problem-solving. This schoolwide model would also provide teachers with a common frame for discussing the solving of complex problems. Ideally, the problem-solving model should prompt the use of metacognitive strategies within the context of the concrete actions that a strong metacognitive thinker takes.

Second, all math teachers should work to implement guided instruction strategies in their classroom. During this study, our students responded positively to the scaffolded supports that were provided during guided instruction. The results of this Record of Study indicate that the use of teacher modeling, probing questions, and targeted feedback were especially beneficial in increasing the independent use of problem-solving and metacognitive strategies. So, a campus wide implementation of guided instruction could be instrumental in increasing our students' capacity for solving problems.

Moving forward, a sustainable model for ensuring the continued implementation of guided instruction is necessary. A campus-wide implementation could be accomplished using a combination of ongoing professional development and coaching with a mentor teacher. I plan to offer a series of ongoing professional development sessions and will be able to work with teachers in their classroom though my role as a math interventionist. Additionally, both teachers who participated in this study now have a great deal of experience using the guided instruction strategies and would be great mentors.

The final recommendation is that teachers should utilize complex problems that foster critical thinking skills. During the intervention, the use of complex problems gave students an authentic opportunity to apply the problem-solving and metacognitive skills that were introduced. The results of this study indicated that our students benefitted from structured opportunities to engage in the process of exploring and analyzing possible solutions. Of additional interest to teachers was the finding that students felt that grade level work was much easier after working on the more complex problems.

Further Research

One limiting factor in applying metacognitive training to other subject areas is domain specificity. Both the existing literature (Jacobse & Harskamp, 2012; Kramarski & Mevarech, 2003; Labuhn et al., 2010) and the results of this study indicate that metacognitive training is not easily transferable to other subject areas. However, there appear to be many applications for metacognitive processes in all subject areas. Further study on the implementation of metacognitive strategies in other content areas seems to be warranted and could lead to a more robust campuswide emphasis on metacognition at our school.

A focus on productive struggle is another potential area of future research. The literature indicates that students benefit from sustained struggle with challenging tasks (Duckworth & Quinn, 2009; Dweck, 2006; Gollwitzer, 1999; Pogrow, 1988). During this study, students were more motivated to engage in challenging activities that were authentic, meaningful, and contained an appropriate level of difficulty. However, there were instances when some students appeared to be locked in a futile struggle with tasks that offered no real benefit. Further research on productive struggle as described by Lynch, Hunt, and Lewis (2018) holds promise for designing differentiated opportunities for all students to wrestle with complex tasks.

Closing Thoughts

Professionally, I have gained a new perspective on student learning and thinking, and the way we approach problem-solving in the elementary classroom. After nearly twenty years in the classroom, I have developed strong opinions on classroom instruction. While my views and teaching practices are principally based on sound research, personal experience and anecdotal evidence have also played a large role in my development as an educator. This project has provided an opportunity to evaluate my practice and reflect on its alignment with the larger body of research. Personally, I have gained a new perspective on project management, and feel much more prepared to take on large, multifaceted projects in the future. This project was important to me personally as the capstone of several years of study on the topic of problem-solving and self-assessment. It has provided me with multiple avenues of further study.

Through this study, our school has gained a deeper understanding of problem-solving on our campus. This project was important within the campus context because it has provided a common frame for viewing the way our students solve problems. The findings confirmed many beliefs that were held by educators but highlighted several areas where our perceptions about our students did not stand up to scrutiny. This project has created a strong foundation for the design of a more comprehensive campus wide problem-solving model. It has also reinforced the importance of providing authentic opportunities for students to engage in meaningful problem-solving activities at an early age.

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APPENDIX A

INTERVENTION SCHEDULE

Week	Lesson Objective	Problem of the Week
1	Defining the Problem	Popsicle Stick Transformations
2	Setting Goals	How Many Handshakes?
3	Taking Action	Farmer Tom’s Travels
4	Monitor and Adjust (Part 1)	Six Ugly Bugs
5	Monitor and Adjust (Part 2)	Monkey Business Logic Puzzle
6	Evaluating Success	Three Sealed Envelopes
7	Posing Problems	Life on Mars Simulation
8	Redefining Problems (Part 1)	Ecosystem Changes
9	Redefining Problems (Part 2)	Advice Columns

APPENDIX B

STUDENT SURVEY

Name: ______________________________

Think about how you feel when you solve problems. Read each statement and check the box that matches your feelings.

		Always	Usually	Sometimes	Rarely	Never
1	I am good at solving problems.					
2	I can solve tough problems on my own.					
3	I usually understand what a problem is asking.					
4	I get frustrated when I have a hard time solving a problem.					
5	Sometimes I know the answer, but I have a hard time explaining why it is correct.					
6	Talking about ideas with others helps me to think about a problem.					
7	I know what strategies to try when I get stuck on a problem.					
8	I can always explain my solution in a way that others can understand.					
9	I have trouble coming up with a plan to solve a problem.					
10	When my answer is not correct, I look back at my work to find mistakes.					
11	I'd rather just give up if a problem is too hard.					
12	I am really good at picking out important information.					

ID # ______ Grade ______ Ethnicity _______ Gender _______

APPENDIX C

PROBLEM-SOLVING PRE-ASSESSMENT

Name: ______________________

Spending Money

Maria wants to buy a new video game that costs $40. Every Monday she puts $4 from her allowance into a jar for savings. During the week she takes $2 out of the jar to buy ice cream at school. How long will it take Maria to save $40 in her jar?

ID # _____ Grade ______ Ethnicity _______ Gender _______ Score ________

APPENDIX D

PROBLEM-SOLVING POST-ASSESSMENT

Name: ______________________ Date: ______________________

Slugs

A small slug tries to climb a twenty foot wall. It is able to climb up three feet each day, but slides back down two feet each night. How many days would it take the slug to reach the top of the wall?

ID# _______ Grade ______ Ethnicity _______ Gender _______ Score _____

APPENDIX E

PROBLEM-SOLVING RUBRIC

	Advanced	Proficient	Developing	Beginning
Identifies Important Information	Identifies all information that is relevant to the problem and presents why information is important within a real-world context	Is able to identify all information that is relevant to the problem; does not include information that is irrelevant	Is able to identify most of the important information; may include some information that is irrelevant	Is unable to identify important information from the problem; cannot differentiate relevant from irrelevant information
Restates the Problem	Restates the essence of the problem within a real-world context and provides relevant supporting or intermediate questions	Succinctly restates the problem within a real-world context	Identifies the problem as presented in the given information	Is unable to identify the problem or incorrectly identifies the problem
Creates a Plan	Creates a plan that addresses the real-world challenges within the problem; Adjusts plan if needed as new understanding is gained	Creates a plan that accurately addresses the problem; plan is revised if needed when new information is gained	Creates a plan based on the problem; The plan may be ill-structured or incomplete; Plan may not be revised if needed	Is unable to develop a plan for solving the problem or develops a plan that does not correctly address the problem
Explores possible solutions	Uses the strategies of the plan in an organized and systematic manner; Evaluates success and makes adjustments based on the evaluation	Uses the strategies in the plan in an organized manner; Adjustments show a progression towards an accurate solution	Attempts to implement the plan; approach seems unorganized or unfocused; makes adjustments that do not move toward a successful solution	Approaches the solution in a manner that is haphazard and inappropriate for solving the problem
Presents a Solution	Presents a solution that accurately responds to all aspects of the problem; the solution is clear and detailed	Presents a solution that accurately responds to all aspects of the problem	Presents a solution that addresses some aspects of the problem; solution may be inaccurate or incomplete, but responds to elements of the problem	Presents a solution that is wholly incorrect or does not address the problem.
Evaluates Solution	Evaluates the effectiveness of the solution and describes why the solution is appropriate within the real-life context of the problem	Evaluates the effectiveness of the solution and can describe how the solution accurately addresses the problem	Attempts to describe the effectiveness of the solution	Presents no evidence of evaluating or describing the effectiveness of the solution

APPENDIX F

CLASSROOM OBSERVATION PROTOCOL

Grade Level: ______________________ **Date:** _________________________

Observer: _______________________ **Time:** _________________________

Lesson Objective and Description:

Description of Problem-solving Activities:

Observation of Teacher and Instruction Guided Instruction, Student Monitoring, Interventions, Instructional Adjustments		
Descriptive Notes	**Reflective Notes**	Revisit

Additional pages are attached: Yes _____ No _____

Observation of Students and Problem-Solving Problem Identification, Planning, Exploration/Solution Attempts, Self/Group Evaluation		
Descriptive Notes	**Reflective Notes**	Revisit

Additional pages are attached: Yes _____ No _____

Analysis of Student Problem-solving Behavior (10 min):

Understanding Planning Clarification Monitoring Evaluation Confusion Misapplication Idle/Unable to Continue	

Additional Description or Reflection:

New Questions:

Ideas for Further Observation:

Revisions/Corrections:

APPENDIX G

TEACHER SEMI-STRUCTURED INTERVIEW PROTOCOL

1. Tell me about problem-solving in your classroom.

2. How successful are your students at: (discuss relevant aspects of the problem-solving process)

- identifying the problem they are trying to solve?
- making a plan?
- the exploration/solving phase?
- presenting their solutions?
- evaluating their work?

3. How do you feel about Guided Instruction?

4. What are your thoughts on the problem-solving lessons?

5. Do you have any other thoughts, questions, or concerns that you would like to share?

APPENDIX H

COGNITIVE LAB PROTOCOL

Cognitive Lab Recording Protocol **Name: ______________**

Grade ______ Ethnicity _______ Gender _____ **Date: _______________**

Brief Problem Description (See Attached Problem)

Student Verbal Record

Researcher Observation

Student Retrospective Record

Researcher Observations

Clarification/Follow up Discussion

APPENDIX I

PROBLEM-SOLVING INTERVENTION – REFLECTIVE NOTES

Grade Level: ______________________ Date: ________________________

Observer: ______________________

Lesson Objective and Description:

Description of Problem-solving Activities:

APPENDIX J

EMAIL CONCERNING IRB DETERMINATION

Dear STEM EdD Cohort. - 2 of your need IRBs and 2 of you do not. See below. This is the information we received from IRB.

MMC and Robert Capraro

Thanks for providing the summaries. Please note that, in any situations that no IRB application is needed and not submitted, the data cannot be used moving forward for research beyond the entity where the quality improvement exercise is being completed. If the individuals would like to be able to use the data for generalizable knowledge and distribution beyond the university and entity where the quality improvement is being conducted, then an IRB application must be submitted.

Here are comments regarding each summary:

David – appears to be within scope of work; quality improvement not research – no IRB submission needed