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Walden University
2016

Abstract

Critical Thinking to Justify an Answer in Mathematics Classrooms

by

Angelique E Brown

MA, Saint John’s University, 2001

BS, Saint John’s University, 1999

Dissertation Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Education

Teacher Leadership

Walden University

September 2016

Abstract

Students' critical thinking in mathematics was a concern for grade 5 through 8 teachers at a Title 1 public school in the northeastern United States because of the students' poor performance on constructed response questions on the state's mathematics exam. In this exam, students were required to justify their answers in writing. When teachers recognize the connection between writing and critical thinking, they can devise strategies to help students develop mathematical literacy. The purpose of this qualitative case study was to explore how 5th through 8th grade mathematics teachers use the GoMath mathematics literacy program to teach the critical thinking skills students need to justify an answer in writing. The conceptual framework of critical thinking theory drove this study examining critical thinking pedagogy in general and special education mathematics classrooms. Qualitative data were collected from pre- and post-observation interviews and classroom observations from 4 purposefully selected mathematics teachers in grades 5 through 8 who taught GoMath. Thematic analysis was used to analyze the data. Teachers reported that oral communication among students before writing justifications and students' critical thinking skills were integral components in solving mathematics problems. Based on the findings, it is recommended that ongoing professional development be adopted to assist teachers in developing strategies for teaching critical thinking skills to help students justify answers in writing when solving mathematics problems. This endeavor may contribute to positive social change by providing teachers with the necessary skills and strategies to enhance students' communication and critical thinking, thus, increasing their academic performance in mathematics.

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Dedication

This doctoral study is dedicated to God, my late grandmother Dr. Ella Morgan, my parents Mr. and Mrs. Raymond Brown, my brother Pierre Brown, and to all of my kids who make each of my days extra bright as a teacher. God's truth (the Bible) is a drawing force in my life and the scriptures that I held on to were Hebrews 11:1: "Faith is the substance of things hoped for and the evidence of things unseen" and Psalm 89:34: "My covenant I will not break, nor alter the word that has gone out of My lips. I am grateful to God for his agape love."

I am indebted to my parents and brother who were always there for me in all aspects of this promise. They would provide the best comfort through hugs and laughs when obstacles tried to distract me, especially when my computer died while I was in the middle of backing up my files. Thank you mommy and daddy for wiping away my tears and holding me in your arms during that upsetting situation. My brother is my biggest cheerleader and would always inquire about my progress.

My late grandmother Dr. Ella Morgan was always my inspiration for pursuing my doctoral degree. She was a woman of resilience and determination. At the age of 77, she obtained her doctoratl degree in theology. I was impressed by my grandmother not only because she obtained the degree at 77 years of age, but because she obtained her degree while being partially blind. My grandmother did not allow her limited eyesight to deter her from accomplishing her goals and dreams. She always taught my family not to allow any circumstance to hinder your goals and that you can achieve all things through Christ Jesus who will strengthen you (Philippians 4:13).

Acknowledgments

I would like to especially acknowledge Dr. Marilyn Simon and Dr. Linda Gatlin who have been a blessing throughout this process. Dr. Linda Gatlin was the professor for my first class of the program. Her excellence, integrity, efficiency, encouragement, correction, and loving nature set the standard for me in regards to what I expected in all staff members at Walden University. Dr. Marilyn Simon has been a great blessing to me over these past five years. She exhibits the same character traits that I stated about Dr. Gatlin. I truly thank you for your support and patience with me during this journey. I love these two women dearly and I pray God's blessings always over their lives.

I would like to thank Dr. Whaley and Dr. Howe for the support you have provided for the end of this journey. I would like to thank Dr. Debra Fisher who has been an excellent source of support and encouragement, and I thank you for all of your prayers during this journey to complete my doctoral degree.

My acknowledgements would not be complete if I didn't acknowledge the wonderful school where I teach. Thank you to the administration for your support, my wonderful teaching friends, and the many kids that I have taught throughout my teaching career who make me LOVE what I do on a daily basis.

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Chapter 1: Introduction to the Study

Mathematics education in the 21st century includes mathematical literacy, which includes writing and discourse as means of deepening students' conceptual understanding of the process and procedures used to find a solution for challenging problems (Clark, 2013). According to Burns (2012) teachers have traditionally taught mathematics using a set of accepted rules and procedures, with an emphasis on obtaining the correct answer. Traditional mathematics pedagogy often does not encourage students to reflect on their thinking through writing and verbal discussion, nor does it encourage students to be active participants in their own learning in the mathematics classroom (Belbase, 2012; Hodgen & Askew, 2007; Oguntoyinbo, 2012).

Within the traditional approach, teachers model what they perceive is an acceptable way to solve a particular kind of mathematical problem. Students are not encouraged to think about an alternative process or procedure for solving the problem. Once students memorize a step-by-step solution, they are not required to understand the how or the why of the process; they need to only recognize the type of problem and apply the memorized procedure to obtain the solution. In contrast to the traditional approach, leaders at the National Council of Teachers of Mathematics (NCTM) and the Common Core State Standards Initiative have advocated for mathematics educators to move away from rote learning and create learning environments that fosters critical thinking for conceptual understanding, which encourages students to think about the processes they use to solve a mathematical problem and then justify their answers in writing (Dickey, 2013). Mathematics students who develop critical thinking skills by communicating their thoughts and justifying their reasoning in writing will most likely become better problem solvers (NCTM, 2014).

Critical thinking is an important element of mathematical literacy necessary for justifying one's mathematical reasoning (Aubrey, Ghent, & Kanira (2012). The local problem I addressed in this study was the limited development of critical thinking skills in students at an urban Title I public school in the northeastern United States, where administrators have instituted a mathematics literacy program. Students' low test scores provide evidence of the need to improve their mathematical literacy and the critical thinking skills needed to justify their reasoning in writing. Although the students at the local research site have historically performed well on the state math exam, the results on the short and extended constructed response questions that require students to use critical thinking to justify their answers in writing fall below state standards. A majority of students perform at either level 1 (below grade level), or level 2 (approaching grade level). These scores fall short of the state's required score of level 3 (at grade level). Upper elementary and middle school mathematics teachers in general and special education mathematics classrooms have expressed a need for support in enhancing their students' critical thinking to justify their answers to mathematical problems in writing. More specifically, the local problem that I addressed was the low short and extended constructed response test scores and the need to enhance students' critical thinking to justify their answers in writing.

Background of the Problem

The results from the Trends in International Mathematics and Science Study (TIMSS) included two overarching issues for mathematics educators with regard to developing or increasing critical thinking and mathematical understanding among students: (a) the lack of verbal communication, and (b) the lack of written communication needed to justify one's answer (Mullis, Martin, & Foy, 2007: Mullis, Martin, Foy, & Arora, 2011). In countries like Japan, student interactions are a primary source of learning that help foster critical thinking. Mathematics education builds on shared interpretations based on students' interactions that enable students to transform even ambiguous information into strategies for problem solving (Pytash & Morgan, 2013).

Because of the pressure for students to perform well on standardized tests, K-12 educators are pushed to teach the necessary math skills. Children typically learn math by rote memory and by emulating how a teacher or a textbook models one acceptable way to solve a particular problem. Within the traditional approach, teachers review the selected problems and students provide a correct answer. In this scenario, teachers rarely expand students' critical thinking by asking them to explain their reasoning for their answers to the mathematical problem (Belbase, 2012; Hodgen & Askew, 2007). In addition, when students offer an incorrect answer, teachers often ask other students for the correct answer without encouraging the previous student to explain the strategy or process used in solving the problem. Wrong answers can provide students with the opportunity to analyze, reflect, and clarify their thinking (Barlow & Drake, 2008).

This practice in teaching mathematics has prompted some to question the role of critical thinking in the mathematics classroom. Burns (2012), for instance, has discussed how in her early years of teaching, she assumed that when a student gave a correct answer, the student had a clear understanding about the mathematical concepts behind the problem. Therefore, she would never inquire about her students' critical thinking and reasoning because the answer given was the answer she was expecting. Burns realized that not asking students to exlain and justify their mathematical thinking was wrong. According to Burns, there might be incorrect mathematical reasoning involved with obtaining the right answer that does not provide students with a clear and solid mathematical understanding of mathematical concepts.

Leaders at NCTM (2014) cited research that advocates higher mathematical standards with an emphasis on critical thinking for problem solving. Despite these reform measures, achievement gaps still persist (Casserly, Horwitz, Soga, & Snipes, 2008). Teachers traditionally have not provided students with guidance in thinking critically in order to justify their answers (Burns, 2012; Faulkner, 2013), and students rarely receive encouragement from their teachers to explain their thinking in a written format (Sriraman & English, 2010). This dilemma is also evident in schools' resources. Most textbooks rely on paper and drill practice, with little or no emphasis on critical thinking and written explanations for mathematical problems (Faulkner, 2013). When a reliance on textbooks is evident in the classroom, most students view mathematics as a means of communication through manipulating symbols in an orderly fashion, not as a subject that involves using words to express and clarify ideas (Schwartz & Kenney, 2012).

Problem Statement

Teaching critical thinking in mathematics was a concern at my research site, because of the students' poor performance on constructed response questions on the state's exam. Administrators in this urban Title I public school instituted a mathematics literacy program to address students' critical thinking in mathematics. Although the students at the local research site have historically performed well on the state math exams, the results on the short and extended constructed response questions that require students to use critical thinking to justify their answers in writing fall below the state standard of a level 3. Based on the school scores data for grades 5 through 8, 46% of the students on the writing component of the mathematics are a level 1, which is below state standards and level 2, which is approaching state standards. Upper elementary and middle school mathematics teachers in both the general and special education mathematics classrooms have expressed the need for support in enhancing their students' critical thinking to justify their answers in writing.

Nature of the Study

In this qualitative case study, I examined mathematics teacher practices in implementing the writing component of a mathematical literacy program. Specifically, I focused on practices mathematics teachers in general and special education mathematics classrooms use to guide students to think critically in order to justify an answer in writing. The sample for this study consisted of four mathematics teachers from grades 5 through 8 from an urban Title I public school. To address the research question, I collected data by conducting two interviews and classroom observations for each participant. Prior to conducting the classroom observations, I interviewed the participants. Following the classroom observations, I conducted a second interview with each participant. I used thematic analysis to analyze all qualitative data, and an open-coding strategy to reduce data and find emerging themes. I triangulated all data among all data sets.

Research Question

This qualitative case study involved investigating the following research question: How do fifth- through eighth grade mathematics and special education teachers use the GoMath literacy program to teach students to justify mathematics solutions in writing?

Purpose of the Study

The purpose of this qualitative case study was to explore how mathematics teachers use the GoMath literacy program to teach critical thinking in writing. In particular, I aimed to understand how critical thinking in mathematical literacy impacts students' mathematical reasoning and the written justification of their answers. Mathematics literacy includes an emphasis on communicating mathematical ideas to provide students with the opportunity to think critically in order to sharpen their understanding of mathematical ideas that they experience (Barlow & Drake, 2008). To promote the opportunity to think critically to justify an answer, students must be encouraged to explore mathematical ideas, deepen their understanding of these ideas, and make mathematical connections within and outside mathematics classrooms through written and verbal communication (Applebee & Langer, 2011).

Conceptual Framework

The study's conceptual framework was based on critical thinking and writing in mathematics. I used this conceptual framework to guide the literature review, and to inform the data collection and analysis methods.

The purpose of mathematics pedagogy is to stimulate students' intellectual curiosity in understanding mathematical concepts (Keiser, 2012). When students are able to determine the mathematical reasoning behind a concept, they are more likely to have a better understanding of the concept. Discovery provides students with the opportunity to internalize mathematical concepts and become active participants in their learning process (Steele, 2007). The use of critical thinking and writing in mathematics is effective for promoting discovery and developing critical thinking skills while developing mathematical understanding (Ahn, Tamayo, & Catabagan, 2013; Steele, 2007).

The connection between critical thinking and mathematical understanding is important because writing in mathematics helps support the view that learning goes beyond reproducing information (Sandmel & Graham, 2011). Writing in mathematics can change the dynamics of the classroom environment because it "can improve students' learning by promoting active knowledge construction that requires them to be involved in transforming rather than [in] a process of reproducing" (Boscolo & Mason, 2001, p.85). As a result of writing in math, students can become less dependent on the teacher and begin to take more responsibility for validating their own mathematical thinking (Keiser, 2012; Rasmussen & Marrongelle, 2006). When students are actively involved in critical thinking, they will begin to reflect on their experiences and actively construct meaning relevant to the mathematical concepts being taught (Hintz, 2014). Zakaria (2007) noted that mathematics students who were taught how to reason and think critically significantly outperformed students who were taught using the traditional lecture method in both mathematical achievement and problem solving. Rasmussen and Marrongelle (2006) found that students demonstrated a richer development of mathematical understanding when critical thinking was an integral component of their instruction.

Definitions of Terms

I used the following operational definitions throughout the course of this study.

Constructivism in mathematics: The view that mathematics teaching is more than providing information and checking to see all students have acquired the information. Instead, teachers create situations whereby students actively participate in mathematical activities that enable them to make their own mathematical constructions (Allen, 2011; Jia, 2010).

Critical thinking: The ability to analyze and synthesize information to reach an answer or draw a conclusion (Hintz, 2014; Keiser, 2012).

Mathematical literacy: Achieving proficient mathematical reasoning through written communication, whereby students consolidate their thinking while reflecting on their work and justifying their thoughts and ideas (Hintz, 2014). According to de Lange (2009), mathematics literacy is a continuous, multidimensional spectrum ranging from aspects of basic functionality to high-level mastery.

Reasoning: The way individuals form conclusions or inferences (Burns, 2012; Keiser, 2012).

Assumptions, Scope, Delimitations, and Limitations

Assumptions

An assumption for this study was that interview responses from teacher participants were accurate reflections of the mathematical literacy program. Additionally, I assumed that teacher participants were implementing mathematical literacy in their daily instruction.

Scope of the Study and Delimitations

The scope of the study involved an urban Title I school in the northeastern region of the United States. The study was delimited to four mathematics teachers who have used the GoMath program for a minimum of two years, and who teach fifth- through eighth grade students. The data were delimited to two interviews and classroom observations of each participant. These three data sets were comprised of a pre-observation interview before the classroom observation, the classroom observation, and a post-observation interview following the classroom observation.

Limitations

A limitation of this study was the case study research design. In case study research, the sample is typically a representative sample and participants are not necessarily representative of a larger population. In this study, I focused on a small group of fifth- through eighth-grade mathematics teachers at a Title I school located in the northeastern region of the United States. The participating mathematics teachers may not accurately represent any larger population. Therefore, caution should be used when generalizing findings beyond the research site.

Significance of the Study

The significance of this study is its potential to contribute to the development of pedagogical strategies to ensure mathematical success for all students. Study findings may contribute to an understanding of how teachers engineer effective classroom practices for eliciting critical thinking by using daily writing activites to help students build mathematical understanding required for problem solving. Findings showed how critical thinking in teaching and learning activities can help students build upon or refine their mathematical knowledge (Aubrey et al., 2012; NCTM, 2014). Findings also showed that activated critical thinking contributed to students' self-analysis of the way they think and become owners of their own learning while serving as an additional instructional resource for one another (NCTM, 2014). This goal was achievable through constructed response questions that require students to to use critical thinking by analyzing and synthesizing information.

Moreover, by recognizing the relationship between writing and thinking, and using national standards that emphasize communication in mathematics, mathematics teachers were able to promote writing as a powerful tool in developing students' critical thinking in mathematical literacy (Vu & Hall, 2012). The use of written justifications of answers has helped the mathematics teachers improve upon their critical thinking instruction practices and make any necessary instruction modifications (Paul, 2004). The use of critical thinking has guided students into monitoring and assessing their own mathematical knowledge to make any necessary revisions in their mathematical understanding (Paul, 2004).

Summary

This qualitative case study involved examining fifth- through eighth grade mathematics teachers' instructional practices relevant to student writing practices used to justify answers to mathematical problems. I sought to examine how the participating mathematics teachers viewed critical thinking within the mathematics literacy program, the importance of critical thinking within the mathematics literacy program, and its relevance in the mathematics curriculum.

Chapter 2 includes a review of the research literature on critical thinking, mathematical communication, and the theory of constructivism. Chapter 3 contains a discussion of the study's research design, and Chapter 4 contains the results of the data analysis phase of the study. Chapter 5 includes an interpretation of the findings of the study and recommendations for further research on the topic.

Chapter 2: Literature Review

Introduction

This qualitative case study involved investigating the following research question: How do fifth- through eighth grade mathematics and special education teachers use the GoMath literacy program to teach students to justify mathematics solutions in writing? The conceptual framework for this study included the concepts of critical thinking in mathematics, literacy in mathematics, and constructivism. My intent for this study was to examine mathematics teacher practices in teaching writing that included instruction to enhance students' critical thinking to justify an answer. In order to achieve the levels of mathematics achievement of students from other countries, K-12 educators and administrators in the U.S. have been pushed to teach the necessary skills required by the standardized assessments (Rondamb, 2014). The push for better test scores may have hampered teachers' instruction in the needed critical thinking skills for students who are problem solving in mathematics. In the 21st century, K-12 educators, administrators, and researchers have acknowledged that mathematics education goes beyond memorizing a set of facts and skills (Faulkner, 2013). Current academic standards are focused on creating classroom discussions that develop students' problem solving and critical thinking skills, which are important in children's analogical reasoning (Butera et al., 2014; Faulkner, 2013). Writing contributes to students' ability to think critically, and it empowers them to take ownership of their learning. Writing enhances students' mathematical understanding as they organize, reinforce, clarify, and explain their mathematical thinking (Mallia, Pawloski, & Daisey, 2012).

All students need access to high-quality mathematics education. The goal of mathematics education should be to develop critical thinking and mathematical understanding among all students. Researchers at NCTM (2014) noted, "Communication is an essential part of mathematics and mathematics education" (p. 60). The NCTM researchers also emphasized the importance of children communicating their mathematical thinking coherently to their peers and teachers. Communication allows students to clarify their thinking and sharpen their understanding. The students will subsequently begin to assimilate new and old knowledge (NCTM, 2014).

Teachers can help children learn language through verbal communication, and teachers can establish communication-rich classrooms by encouraging students to think critically, to share their ideas, and to seek clarification for further mathematical understanding (Thompson et al., 2008). This type of classroom environment provides students with opportunities to discuss their mathematical thinking. Such an environment allows children to write about how they solved a problem, which helps them clarify their thinking and develop deeper understanding (Burns, 2012; NCTM, 2014).

Title Searches, Articles, Research Documents, and Journals Researched

I conducted an extensive literature review which revealed several studies regarding critical thinking, mathematical literacy, and writing in mathematics. To obtain scholarly journal articles, I used Walden University's library resources to access databases including ERIC, Education Research Complete, Education: A SAGE full-text database, ProQuest, and PsycARTICLES. Search terms included *critical thinking, mathematics literacy, writing, achievement,* and *mathematics communication*. I also conducted internet searches using search engines such as Yahoo, Google, and Google Scholar, and reviewed websites including those of the NCTM and the Association for Supervision and Curriculum Development. This literature review helped me articulate the need for the study and build upon prior research in the field of critical thinking, mathematical literacy, and mathematics education. These search led me to organize the scholarly literature into the following categories: *mathematics literacy, mathematics achievement, mathematics communication, critical thinking, mathematical reasoning,* and *mathematics writing*. This section is organized according to seven major categories of information pertaining to the problem, purpose, and research questions: (a) traditional mathematics instruction, (b) the importance of critical thinking and mathematical communication, (c) the benefits of mathematical communication, (d) the constructivist theory of learning, (e) critical analysis, (f) applying constructivist practices to mathematical communication, and (g) related research.

Traditional Mathematics Instruction

Traditional mathematics instruction consists of memorizing basic math facts, rules, and procedures, and obtaining enough mathematics knowledge to allow individuals to make informed decisions (Sriraman & English, 2010). The primary means of learning mathematics is rote learning, which involves routines and exercises memory without necessarily understanding or reflecting (Marshall, 2006). In rote learning, teachers typically model a procedure, and students then parrot the procedure with similar problems for classwork and homework. Teachers using traditional instruction rarely address how or why the procedure works in the mathematics classroom (Jia, 2010).

Many teachers have experienced the traditional approach to mathematics instruction that emphasizes memorizing facts with rigid rules and procedures (Barrett & Long, 2012). In traditional teaching, teachers initiate, explain, and analyze through direct instruction (Barrett & Long, 2012; Jia, 2010). Such teachers are pivotal in organizing and guiding the whole teaching process based on structural knowledge, which results in teachers completing the math for the students instead of the students completing the math for themselves (Allen, 2011; Jia, 2010). Students typically receive numerous problems or textbook pages to reinforce mathematical concepts or procedures, with the implied notion that students are gaining mathematical understanding (Allen, 2011; Jia, 2010).

Barrett and Long (2012) posited that teachers teach mathematics based on their view of mathematics and their perception of how students learn mathematics. This approach stems from teachers' personal experience of how they learned mathematics. If teachers view mathematics as a set of rules and procedures to learn and follow, then teachers will view their role as transferring knowledge to students (Barrett & Long, 2012). However, current constructivist research has indicated the traditional approach is ineffective. Students appear to master facts and procedures, but the students' mathematical understanding behind these concepts and procedures is not always evident (Hennessey, Higley, & Chesnut, 2012; Jia, 2010). Overwhelming, assigning students countless worksheets or textbook pages with drills is not effective for imparting mathematical understanding (Allen, 2011; Keiser, 2012). Basic math facts are important for problem solving and computational procedures. Nonetheless, students should have a clear understanding of the mathematical reasoning behind the concepts and procedures (Jia, 2010).

When teachers instruct students to follow a formula and then apply it to solve textbook problems, this approach will not necessarily prepare students to handle problems in real life (Sriraman & English, 2010). Mathematical literacy involves more than executing mathematical procedures; literacy includes applying knowledge, methods, and processes in various contexts in meaningful, real-life, and reflective ways (Clark, 2013). Learning mathematics is not isolated from the students' experiences.

National Council of Teachers of Mathematics Recommendations

With the exception of signs and symbols, teachers have neglected communication in mathematics (Hintz, 2014). Because of limited emphasis on critical thinking skills and mathematics literacy in mathematics education, NCTM researchers have developed a set of standards to help improve mathematics instruction, emphasizing that communication is an essential element in student learning (NCTM, 2014). The Communication Standard from the *Principles and Standards for School Mathematics* (NCTM, 2014) describes communication as the use of language to express ideas, and frames it as powerful tool to help foster the learning of mathematics. Within this standard, there are four process areas to help teachers incorporate critical thinking on a daily basis. The four process areas are: problem solving, representation, reasoning, and connections. Communication provides students with opportunities to articulate, clarify, organize, and consolidate their mathematical thinking. Students can communicate in various forms, such as orally, or with gestures, pictures, symbols, and writing. When students listen to other students explaining mathematical ideas, they gain exposure to alternative methods and strategies. Collaboration with their peers enables students to become increasingly proficient with the content, thus allowing them to master and express mathematical language and concepts. By making mathematical thinking readily observable, communication promotes further development of a particular thought process.

Common Core State Standards and Mathematics Learning

The purpose of the Common Core State Standards is to provide educators and administrators with a clear set of shared goals and expectations related to the knowledge and skills students need in English language arts and mathematics at each grade level so they can be equipped for college, career, and life success (Phillips & Wong, 2012; Rothman, 2012).. The Common Core State Standards address the problems prevalent in English language arts and mathematics teaching (Rothman, 2012). The standards provide expectations for raising the level of learning for all students. One expectation is that all students will achieve mathematics literacy by understanding the content deeply, and will be able to apply their knowledge to think critically and solve complex problems (Rothman, 2012). The standards in the early grades are that students can apply familiar algorithms by showing that they understand what the algorithms represent and that they can apply their understanding to mathematics used in real-life applications (Smith, Wilhelm, & Fredricksen, 2013).

The goal of the developers of the Common Core State Standards for mathematics was to develop students who are mathematical learners, rather than students who are capable of providing mere answers to problems (Smith, et al., 2013). A crucial focus of the Common Core State Standards is to require student writing instruction that is more challenging, and to assist students to demonstrate their mathematical knowledge through oral and written communication. To take responsibility for learning, students will receive encouragement to discuss, examine, explain, and defend their work (Phillips & Wong, 2012). A main emphasis of the common core is to promote high-level mathematical tasks and higher levels of learning by creating higher standards and better measures in order to develop students who can think more critically (Rothman, 2012).

Importance of Critical Thinking and Mathematical Communication

Using a qualitative case study approach, I sought to examine upper elementary and middle school mathematics teachers' practices in writing instruction that use critical thinking to justify answers to problem in general and special education mathematics classrooms. Critical thinking is a major intellectual and practical skill for education and in everyday life. According to Rondamb (2014), evidence indicates that the majority of students entering into higher education and the workforce lack critical thinking skills and an understanding of what it means to think critically. Often, critical thinking is overlooked at the K-12 school levels where students are taught how to learn and how to analyze information. When these students enter higher education or workforce environments, they realize they must first learn critical thinking skills before they can effectively acquire and use content information or knowledge (Rondamb, 2014). For students to think critically, educators must implement daily activities that require students to understand *why* something has occurred as opposed to only understanding *what* has occurred (Rondamb, 2014). This type of learning will help students deepen their understanding and help them better analyze the circumstances surrounding the problem and different viewpoints about the occurrence of the problem (Adams, Bondy, & Tutak, 2011).

Mathematics literacy includes being able to communicate, and communication is essential for critical thinking practices that students use to analyze, evaluate, and synthesize important mathematical concepts, ideas, and problems in written and oral formats (Steele, 2007). Mathematical communication is a necessary element in mathematics education and mathematics literacy (Goldsmith, 2013). Mathematics education goes beyond teaching basic math facts and procedures quickly and efficiently (Marshall, 2006). The basic processes of addition, subtraction, multiplication, and division are vital, but these do not comprise the core of constructing mathematical understanding. According to Bruner (1966), understanding is seeing the relationships and connections to other things that students know. Mathematical communication provides students with the opportunity to devise and test strategies, as well as learn different strategies from other students helpful in consolidating thinking and constructing a deeper mathematical understanding (Hintz, 2014).

Benefits of Mathematical Communication

When considering the benefits of mathematical education, three distinct benefits are addressed in the research literature. First, the benefits of oral communication and its vital role in communicating knowledge are considered. Second, the benefits of written communication are central to the literature on the importance of writing across the curriculum. Third, the benefits of student reflection include the process of constructing mathematical thinking.

Language has a vital role in communicating knowledge. Language shapes the habits of thoughts (Piaget, 1959). As a cultural tool, specifically a human instrument of communication, language serves as a means of representation and a means of communication (Hintz, 2014). When students use mathematical language daily, language becomes a means of regulation whereby students begin to develop proficiency in their thinking (Burns, 2012; Keiser, 2012).

Communication supports students' learning and builds mathematical meaning (Burns, 2012; Hintz, 2014). Mathematical communication is evident in the classroom when teachers activate mathematical understanding and verbal communication (Keiser, 2012). For students to be able to speak the language of mathematics, students must learn to engage in verbal communication daily. Embedding verbal communication within the curriculum will help develop students' mathematical language skills, and students will become critical thinkers (NCTM, 2014).

Spoken language is an essential part of students' actions when they work in groups (Hintz, 2014). Mathematical understanding can increase when students share the different strategies or processes that they used to solve problems (Kinzer, Virag, & Morales, 2011). When students express their thinking with their classmates, the exposure to various methods they might not have thought of or recognized increases. Providing students with opportunities to experience the relationship between critical thinking and writing (Lardner, 2008) helps students gain an understanding on how others make sense of the concept they are learning (Kinzer et al., 2011). Mathematical literacy provides students with the opportunity to clarify their thinking and construct long-term knowledge (Vygotsky, 1978). Writing allows students to take ownership of their learning by engaging them in a practice that requires reflection and thought (Peterson, 2007). According to constructivism, when students reflect on their experiences, they are actively constructing meaning (Jia, 2010).

Students need to articulate their solutions to help develop skills of synthesis and integration (Roake & Varlas, 2013). When students are not articulating ideas clearly, teachers have an opportunity to encourage other students to ask questions for further clarification and understanding (Keiser, 2012; McNeal, Williams, & Wood, 2006). When teachers and students challenge a student's thought process, the student has the opportunity to hone his or her mathematical thinking by learning to express thoughts coherently. According to Bloom's (1956) taxonomy, when teachers challenge students' thinking, students must function at higher cognitive domains, which are the analysis and synthesis levels. Mathematical discussions are evident in classrooms when students become comfortable sharing their thoughts with others, listening to their classmates' ideas, revisiting their own thinking, taking ownership of their learning, and walking away with a more profound mathematical understanding (Larson et al., 2012).

Mathematical discussions are social activities that are necessary for learning (Pytash & Morgan, 2013). The discussions contribute to building students' critical thinking and mathematical understanding as they begin to make sense of the mathematics they encounter (Bruner, 1966, Butera et al., 2014). Having students engaged in socially meaningful activities promotes higher order thinking skills (Vygotsky, 1978). All students will benefit from mathematical discussions. Students can sometimes provide a better explanation of problems, solutions, and processes in their own words. Students communicate to learn, as well as to learn how to communicate mathematically, and a goal of mathematics is for students to communicate using mathematical language (Allen, 2011).

Benefits of Written Communication

According to Cooper (2012), the demand for incorporating writing into all content areas has increased in the recent years as educators and researchers have recognized the importance of writing across the curriculum. However, writing with the focus of critical thinking is often missing in the mathematics classrooms (Cooper, 2012). Incorporating critical thinking to justify answers to problems helps students develop their comprehension skills and ability to articulate their thought processes when solving a mathematical problem (Adams, et al., 2011; Cooper, 2012). According to the leaders of NCTM (2014), educators can incorporate critical thinking to justify answers to help students deepen their mathematical understanding and reasoning and reflection needed to clarify their ideas (Cooper, 2012). Critical thinking is an essential component in writing in mathematics to justify an answer (Rondamb, 2014) in order to help enhance students' mathematical understanding and reasoning skills.

Writing as part of mathematics learning can extend and deepen the understanding and application of mathematical concepts (Keiser, 2012; Mallia, et al., 2012). The process of writing requires gathering, organizing, and clarifying thoughts. Writing prompts students' ownership of ideas by allowing them to put ideas into their own words and gradually incorporate the idea into the architecture of their knowledge (Rothman, 2012). After explaining the mathematical process, students begin to discover what they understand, as well as what they do not understand (Keiser, 2012). Writing is central to the understanding process in general. Students often do not know how to articulate their thoughts until they put words on paper (Mallia, et al., 2012). Writing requires students to take their thoughts from their heads and put them on paper so they can see and interact with them (Keiser, 2012). Writing is not simply a way of expressing what a person has learned; writing itself is a fundamental mode of learning (Schwartz & Kenney, 2012).

Integrating writing into mathematics instruction provides a forum for helping students gain clarity about their level of understanding. Writing helps students construct personal meaning with their own language. When writing is present, mathematics extends beyond the automaticity of basic facts, rules, and procedures (Oguntoyinbo, 2012). When students write, they begin to see the reasoning behind why mathematical concepts and formulas work (Rothman, 2012). As a result of understanding the reasoning behind mathematical concepts, students begin to make mathematical connections to the real world, beyond an abstract world of formulas and procedures (Ahn et al., 2013).

Writing highlights hidden misconceptions and helps students to think metacognitively (Keiser, 2012). Metacognitive development, or increasing one's abilities to reflect on one's own learning, expedites the transfer of knowledge across context (Allen, 2011). Students who have experienced writing about their strategies or methods enhance their metacognitive skills, and their ability to speak about mathematics becomes clearer and more fluent (Jia, 2010). Students begin to explore and discover new knowledge in conjunction with their previous knowledge when they write out steps showing the mathematical process used to solve problems. When teachers provide instructional opportunities to write in math, students become more confident in their writing and their mathematical understanding increases (Allen, 2011; Jia, 2010).

Benefits of Student Reflection

Another component of critical thinking in mathematical literacy involves reflection. The process of reflection allows students to construct their own mathematical thinking. According to Dewey (1987, Article 1, para. 2), when students and teachers reflect, they reexamine their thinking to clarify any errors or make written explanations clearer and more concise. Reflection, like communication, exposes how students construct their mathematical thinking (NCTM, 2014) and provides students with the opportunity to explore the connection between their prior knowledge and the current knowledge being constructed (Bruner, 1966; Keiser, 2012). When students reflect, they are learning to communicate mathematically and think critically.

Reflection also entails justifying an answer to clarify one’s mathematical thinking (Roake & Varlas, 2013). Aside from stating the correct answer or reciting memorized procedures and rules, mathematics entails making sense of strategies required to become critical thinkers (Checkley, 2006; Hintz, 2014). Justifying an answer to a mathematical problem is important because students must synthesize their thinking, which is in the upper echelon of Bloom’s (1956) cognitive domain. Justification requires students to demonstrate each step of their mathematical process, explain the mathematical reasoning for each step, check for any computational errors, and critique any errors. By revising their thoughts, students clarify any misconceptions and hone their mathematical thinking skills (Schwartz & Kenney, 2012). When teachers encourage students to defend their mathematical positions, teachers can enhance the quality of mathematics in the classroom (Allen, 2011).

Keiser (2012) worked with sixth-, seventh-, and eighth-grade students and discovered incorrect solutions could produce rich and meaningful conversations between students, which provided an opportunity for exposure to new strategies whereby students could examine relationships between different thought processes. The discussions helped students reflect on their ideas with simpler cases to help avoid making the same error. The discussions provided the students with the opportunity to identify relationships between their approach and another student's approach in solving a problem, which helped foster a greater understanding of the topic. Additionally, students begin to realize that their thinking has value in the classroom (Keiser, 2012), which can help build students' confidence in improving their problem-solving and mathematical-processing skills.

Critical Analysis

The research literature reviewed shared several commonalities in increasing critical thinking and mathematical communication in the classroom. One commonality was the assertion that rote learning does not promote critical thinking and mathematical understanding. A second commonality was the claim that verbal and written communication helps promote critical thinking, develops mathematical language, enhances mathematical understanding, and help students revise their thinking through reflection to gain a variety of new strategies. A third commonality in the literature addresses teachers' lack of mathematical understanding and appropriate professional development in incorporating critical thinking in the mathematics classroom and how this deficit hinders mathematics learning (Switzer, 2010).

Groen and Kieran (1983) and Vygotsky (1962) disputed Piaget's (1959) view on how students learn. According to Piaget, learning math does not involve teachers transmitting knowledge, but involves a child's ability. Groen and Kieran noted children learn math using their prior knowledge and proffer from teachers helping them apply their prior knowledge to new or similar problems. In addition, Piaget believed children learn and understand math based on their particular stage of development (age). In contrast, Groen and Kieran indicated a child's math readiness has to do with ability, not chronological age. According to Bruner (1968), "Any subject can be taught to anybody at any age in some form that is honest" (p. 185), which provides support for Groen and Kieran's view.

Vygotsky (1962) noted that the growth and equilibrium of abstract cognitive structures are not the only basis for development. Cognitive development relates to the concepts of thought: what one thinks about and how one thinks about it. Piaget (1959) separated development and education, as he saw education as having no impact on a child's development. Vygotsky noted Piaget believed mental functions do not change based on a child's development, but only structures change, and thus, the function acquires a new character. Vygotsky saw an internal contradiction in Piaget's view of separating development and education. One basic principle of Piaget's theory is that the intellectual development of a child occurs through a progressive socialization of thought centered on itself at the beginning (Vygotsky, 1962). In contrast to Piaget, Vygotsky's socialization of thought takes place mainly at school because children participate in a culture and share certain ways of thinking with other members of the culture (Vygotsky, 1962).

Applying Teaching Practices in Mathematical Communication

There is concern about the state of mathematics education in the United States. Due to low international test scores and a lack of effective teaching practices, educators and leaders have made a conscious effort to focus on critical thinking, student learning, and constructing knowledge in mathematics (Allen, 2011). Instructors should promote and encourage students to develop a repertoire of powerful mathematical constructions for posing, constructing, exploring, solving, and justifying mathematical problems and concepts and should seek to develop in students the capacity to reflect on and evaluate the quality of their constructions (Allen, 2011; Larson et al., 2012). Learning is contingent upon the activity and involvement of the learner (Confrey, 2006; Oguntoyinbo, 2012). Good mathematics instruction promotes critical thinking through active learning experiences and communication through meaningful interactions with real-world problems. Students construct knowledge when they communicate their ideas and methods for solving problems (Hennessey et al., 2012).

Adapting a constructivist theory of knowledge has major implications for mathematics instruction. It follows from the theory that students are always constructing an understanding from their experiences (Allen, 2011). According to constructivism, teaching as telling is ineffective, whereas teaching to think critically and promote discovery is effective. When applying constructivism to teaching, teachers must reject the assumption that they can simply passively impart information to learners and expect understanding to occur (Dewey, 1987; Joldersma, 2011). Communication is a complex process. When teaching students how to communicate, teachers need to model for the students by paraphrasing key ideas; summarizing key ideas, steps, and concepts; and asking good questions (Allen, 2011; Jia, 2010). Students need to construct their own knowledge, but it is important that they construct their knowledge correctly (Barrett & Long, 2012; Burns, 2012).

Improving Mathematics Instruction

Constructivists believe mathematical learning involves the active manipulation of meaning and understanding, not just numbers and formulas (Barret & Long, 2012). Every aspect of learning entails understanding, and the acquisition of rote learning does not ensure students will use the skills appropriately in mathematical settings (Keiser, 2012). Students will begin to reject their own mathematical thinking when they believe they must learn mathematics in a rote manner (Hintz, 2014; Keiser, 2012).

Educators and teachers can no longer rely on the fact that a student has demonstrated performance, such as adding fractions correctly or solving a quadratic equation to ensure everything is just as it needs to be (Thompson et al., 2008). Having a correct answer or not, students may hold some wrong ways of thinking about mathematics, and these errors can be powerful and harmful over time (Burns, 2012).

Teachers might have viewed their role as being responsible for transferring knowledge to students. Traditional instruction included an assumption that learning facts, rules, and procedures would lead to natural success in mathematical understanding (Barrett & Long, 2012). However, according to constructivism, educators must help students develop and construct powerful ways of thinking. Mathematics education should provide students with the determination to acquire a deeper understanding of themselves and their own mode of learning and thinking (Rothman, 2012; Steffe, 2010).

Developing mathematically literate students requires experiences wherein students can behave as mathematicians (Ben-Hur, 2006). Teacher interventions are crucial in helping guide students to think about their own thought processes, so they understand and transform their knowledge (Soares et al., 2012). For students to develop beyond procedural knowledge, they must have experiences that support the development of conceptual understanding (Thompson et al., 2008). This achievement can occur through exploring concepts, making conjectures, and explaining their reasoning. Teachers can help foster experiences that promote mathematical understanding by creating tasks that require written communication (Soares et al., 2012). Teachers might encounter resistance from students who do not want to explain their reasoning through writing because they might not see the value and importance of writing in mathematics. Nonetheless, the goal is to develop students who can make sense of what they are learning and to stimulate their mathematical thinking (Schwartz & Kenney, 2012).

When students make mathematical errors, teachers can foster rich conversations in the classroom (Burns, 2012). The conversations can attend to the cognitive demands students experience through talking, listening, and making mistakes (Hintz, 2014). Discussing mathematical errors is an essential role in helping improve students' reasoning. According to Hintz (2014), "If only correct ideas regularly receive attention, the mathematics that gets explored is limited, and the students whose original ideas were incorrect may hold on to incorrect mathematics." (p. 320). Investigating mathematical errors provides students with the opportunity to work collectively toward a solution. However, sharing incorrect answers in class can be difficult. Teachers must develop a positive environment in which they value and welcome mutual respect and mistakes. This type of environment shows the students that they have support in making sense of the mathematics (Hintz, 2014; Larson et al., 2012).

Constructivists recommend creating a learning environment in which students acquire basic math concepts, algorithmic skills, and habits of communicating and reflecting (Allen, 2011; Phillips & Wong, 2012). The goal is to create a classroom that involves promoting understanding. Teachers can help construct understanding by having students actively engage in constructing relationships between and among mathematical ideas by reflecting on problem situations, extending knowledge by relating new solutions to prior knowledge, and articulating their thoughts about the mathematics they explore (Barrett & Long, 2012; Soares et al., 2012). When learners construct, reflect on, and articulate understanding, they take ownership of their knowledge (Allen, 2011).

Language of Mathematics

The language of mathematics challenges many middle school students. Most students view mathematics as a foreign language with unfamiliar symbols, signs, words, and phrases (Schwartz & Kenney, 2012). Communication requires students to use the language of mathematics that includes symbols, signs, words, and phrases. As communication is fundamental to learning mathematics, teachers should consider all students as mathematical language learners, regardless of their level of English proficiency (Thompson et al., 2008). As toddlers, students learn spoken language through immersion in a language-rich environment. To develop fluency in mathematical language, middle school students need to experience immersion in the words and symbols of mathematics in the classroom (Switzer, 2010).

In mathematics, writing provides an opportunity for students to think critically in order to help make sense of the mathematics and exchange mathematical ideas. When teachers provide students with opportunities to think critically to justify an answer in writing in the mathematics classrooms, the teachers provide a lens for accessing and assessing what students understand and how they understand the mathematics they are learning (Burns, 2012). When students describe, explain, or justify their thinking, they have the ability to make visible what they know and understand (Schwartz & Kenney, 2012).

Middle School Mathematics

Middle school mathematics is a critical and important period in the mathematical education of students. Students begin to solidify their understanding of the concepts they initially studied in elementary school and begin a more formal study of geometric and algebraic concepts (Thompson et al., 2008). During this stage, adolescents are beginning to value peer opinions and interactions. Therefore, they need opportunities to communicate with their peers by building learning communities in which students work with their peers and teachers to make sense of mathematics (Schwartz & Kenney, 2012).

The primary goal of mathematics learning at the middle school level is to help students transition from an arithmetic-based content at the elementary level to the algebra-based content at the high school level (Schwartz & Kenney, 2012). The middle school standards objective is to prepare students for rigorous math courses at the high school level (Sloan, 2010). A developmentally responsive mathematical instructional practice requires that middle school students actively engage in their learning (Faulkner & Cook, 2006; Keiser, 2012). The basis of middle school math reform movements is recommendations of the constructivist theory in which students construct, reflect, and evaluate their own knowledge through meaningful experiences (Pytash & Morgan, 2013).

Researchers at the National Center for Education Statistics (2010) revealed children as young as eight or nine years of age can abstract concepts of mathematics, and there is a great need for their exposure to progress toward more conceptual knowledge than skills-based knowledge, which can help increase higher mathematical thinking at the middle school level. According to the National Mathematics Advisory Panel (2008), there is a focus on fewer math topics and skills and on more engagement of students in mathematics literacy and communication to develop students' metacognitive abilities, such as being able to reflect and explain one's own thinking. The focus of this proposed study will be on middle school mathematics.

Improving Teacher Development

Constructivists support changing teacher education. Learning from experience is important. Therefore, current and future teachers need to receive rich mathematical experiences. Teachers must learn effective practices to see and interpret elements of practice (Doerr & Lesh, 2003; Faulkner, 2013). It is easy for a teacher to notice rhetoric of change and to believe change is necessary, but it is difficult to recognize how much or how little of one's own teaching actually changes (Sriraman & English, 2010). When a new teaching practice is implemented in a curriculum it's important for teachers to receive professional development about the new teaching practice and how to utilize the teaching practice to its full effect (Rondamb, 2014).

Teachers must stay abreast of reliable, current research about the ways students learn so they can acquire insight into how students think so students can receive quality mathematical education (Ahn et al., 2013; Marshall, 2006). A lack of mathematical understanding among teachers hinders mathematical achievement (Han, 2006). Teachers need to receive mathematical training that can help them acquire understandings behind concepts and procedures (Gardner, 1993).

Professional development must expose teachers to solving authentic mathematical problems, communicating their thinking verbally and in written format, and reflecting upon their solutions. Communication-rich mathematics classrooms are environments with respect and trust. In these environments, students feel safe and empowered to explain their struggles, partial understandings, conjectures, and insight about mathematics (Roake & Varlas, 2013). These types of problems do not involve rote learning, but instead involve genuine learning where one does not know, at the outset, how to find the solution. The purpose in solving these problems is not only to challenge students' mathematical thinking, even though this is important. The purpose is to create discussions about how students might approach such problems, which misconceptions might arise and which must change, and which prerequisite skills are necessary (Burns, 2012).

When teachers engage in rich and meaningful professional development, they can develop a deep understanding of the rich, interrelated set of concepts and the ways in which children develop understandings of these concepts (Ahn et al., 2013; Hennessey et al., 2012). Teachers who receive high-quality professional development can understand mathematics, understand what their students are trying to do, and understand their thoughts about mathematics (Kinzer et al., 2011). The goal is for children to care about mathematics. Therefore, educators must care about children and their mathematical understanding (Soares et al., 2012).

Teacher Reflection

Teachers need to examine their practices, set growth goals, and use focused practice and feedback to achieve those goals (Marzano, 2012). Reflective thinking in teaching stems from the works of Dewey (1933). Dewey viewed reflection as creating a meaning for an experience whereby the learner moves to a deeper understanding of the relationships and connections between that experience and other experiences and ideas. As teachers are constantly learning about teaching and their teaching practices, reflection is essential to the development of expertise in teaching (Danielson, 2009; Marzano, 2012).

Answering the study's research question will involve an attempt to address teachers' practices in writing through the use of critical thinking to justify an answer in a mathematics classroom. Reflection is an important component of professional development. According to Ghaye (2011), reflective practices help teachers understand the links between how they teach and how they might improve their teaching effectiveness. Reflective practices provide teachers the opportunity to understand the importance of high-quality teaching and ideas and options for improving their teaching (Ghaye, 2011). According to Zwozdiak-Myers (2012), reflection prepares teachers for the challenges of the 21st-century classroom. Reflective teachers translate pedagogical knowledge into their own teaching practice. Effective teachers know when to make quick decisions and when to step back and reflect (Danielson, 2009). Teacher reflective practices correlate with teacher pedagogical skill improvement, which has a direct effect on student achievement (Marzano, 2012).

Community of Learners

The growing pressure to raise academic achievement for all students has focused educators' attention on student learning. The ultimate goal of teachers and administrators on all levels is the improvement of student achievement, and they know they must ensure every student reaches these challenging standards (Rothman, 2009). According to Rothman (2009), there is an assumption that the desire to avoid sanctions will encourage schools to do the right thing in increasing student achievement. However, it is not evident that educators know what will raise achievement for all students, especially in struggling schools (Bambrick-Santoyo, 2012). Education reformers are constantly introducing new programs and policies to school communities and these changes have seldom led to improvement in student learning because no one addresses the instructional core (Rothman, 2009).

To produce desired improvement outcomes, education reformers should establish, encourage, and value interactions among teachers, students, school administrators, district administrators, and parents. Everyone in the school community needs to take ownership in helping to raise student achievement and do their part for the improvement to succeed (Bambrick-Santoyo, 2012; Rothman, 2009). Discussions among all members of the school community can help prepare students to develop a deeper understanding academically and increase student achievement (Switzer, 2010).

Evidence from school communities that work together in improving instruction can yield an increase in student achievement (Bambrick-Santoyo, 2012). For example, instruction improved at all levels in Community School District #2 in Manhattan, New York. A new curriculum and investments in professional development for all teachers were essential to improving instruction (Rothman, 2009). In addition, all administrators at all levels were accountable for achieving these improvements and they valued their positions for helping to improve instruction at all levels. The district rose from 10th to second in the city in reading achievement and from fourth to second in mathematics achievement (Rothman, 2009). Administrators credited collaboration among school communities for the success.

Related Research

When I examined prior research related to this study, two overarching research topics were identified. First, studies on the effects of mathematical instructional strategies were examined. Second, research on the relationship between writing and mathematical achievement was explored.

Effects of Mathematical Instructional Strategies

Evidence indicates improvement in mathematical achievement occurs as a result of a change in mathematical instruction. Ferrara (2010) studied the effects of implementing pedagogy and addressing different learning styles to improve mathematics achievement of eighth-grade students in a Title I middle school in a suburban district. Ferrara analyzed both qualitative and quantitative data to determine how teaching to different learning styles affects student outcome. The two groups for the study were an experimental group and a control group. The experimental group consisted of 62 students that received the learning styles intervention instructional strategies. The control group consisted of 33 students who received no intervention and had the traditional instruction. Both groups completed a pretest and posttest. At the end of each 10-week grading period, two benchmark assessments compared the level of mathematical achievement (Ferrara, 2010). The quantitative component was the benchmark scores. The qualitative component was a classroom observation during the intervention and an anonymous open-ended reflection survey for teachers at the end of the intervention.

Both the experimental and the control groups experienced slight improvement in mathematical achievement from the pretest and posttest benchmark assessments (Ferrara, 2010). Ferrara (2010) found the experimental group's average performance from the pretest and posttest indicated the scores increased at least 5 points. The control group's average performance from pretest to posttest indicated the scores increased at least 1.37 points. Although there were improvements in each group, the analysis of covariance (ANCOVA) test did not reveal a significant difference between the learning styles instructional strategies and the traditional instruction in mathematics achievement.

Writing and Mathematical Achievement

Research indicated that writing in mathematics has positive effects on student learning. Roskin (2010) used a mixed-methods study to determine the effects of writing in mathematics and its relationship to student achievement and engagement in mathematics among fifth-grade students in a private school from prekindergarten to eighth grade in a metropolitan area. Twenty-four students participated in the study. The students completed a pretest in January and a posttest in February. Both tests were identical, and the purpose was to measure concept attainment (Roskin, 2010). The quantitative component was the pretest and posttest scores. The qualitative aspect was a questionnaire students completed on their attitude toward math at the end of the unit. Another qualitative component was the researcher's journal, which consisted of evidence of student motivation and achievement prior to, during, and at the end of the unit (Roskin, 2010).

The results of the study showed an improvement in mathematical achievement from the pretest and posttest (Roskin, 2010). Roskin (2010) found the results were higher in the posttest than in the pretest. The two-tailed *t* test showed a significant improvement

($t = 3.63$) in student achievement. However, the results showed many students did not view writing in math as helpful, as indicated by the standard deviation of 1.43.

Bettencourt (2009) studied the effects of writing in the middle school grades and the relationship to mathematical understanding of eighth-grade students in a middle school in a rural district. The study included a quantitative approach to acquire and analyze the data in the study (Bettencourt, 2009). The two groups for the study were an experimental group consisting of 19 students who received writing as an additional instructional strategy for mathematical understanding and a control group consisting of 22 students who received instruction that did not require writing. Both groups completed a pretest as a baseline and a posttest to measure mathematical growth and achievement (Bettencourt, 2009).

Both the experimental and the control groups experienced improvement in mathematical achievement from the pretest and posttest (Bettencourt, 2009). The paired *t* test showed a gain of 1.55 raw points for the control group, while the experimental group showed a gain of 4.89 raw points. The results were a minimum score of 27 on the posttest when writing was not an instructional tool compared to a minimum score of 39 when writing was an instructional tool. The maximum score on the posttest was 80 when writing was not an instructional tool compared to the maximum score of 90 when writing was an instructional tool (Bettencourt, 2009). Although each group showed improvement, the independent *t* test and ANCOVA did not show a significant difference in mathematical achievement between the experimental and the control groups.

Summary

Due to changes in economics, politics, and technology, a concern has developed regarding the perception of a global achievement gap (Sammons, 2011). The concern is the gap between what teachers teach students compared to what students need for success in the world (Wagner, 2010). All students need to learn how to solve problems using critical thinking skills, as well as how to communicate their thought process clearly and concisely (Wagner, 2010). To become lifelong learners, students need to apply what they learn to new situations and challenges rather than merely reciting what they memorize (Wagner, 2010).

A classroom where critical thinking and mathematical literacy is the norm can help students develop confidence and competence as mathematical thinkers (Sammons, 2011). For students to achieve mathematical understanding, their views of mathematics and the way they learn must change. Teachers should view students not as passive receivers of knowledge but as learners who actively construct knowledge (Ahn et al., 2013; Dewey, 1987). To achieve this, students need to communicate their thoughts verbally and in written format daily. When students practice writing about mathematics on a daily basis, they can become proficient at expressing their mathematical thinking clearly and concisely, and their conceptual understanding deepens (Sammons, 2011).

The literature review revealed that when students communicate their thoughts both verbally and in writing, they are more likely to gain a deeper and more meaningful understanding of mathematics (Burns, 2012; Sammons, 2011). In addition, students' exposure to the way other students think mathematically, as well as the way others learn new methods, increases. Research has shown both verbal and written communications provide the same benefits in mathematical understanding. The emphasis on mathematical communication is to develop students' critical thinking and understanding of mathematics while improving their communicative abilities (Wagner, 2010). For student success in mathematics teaching and learning, writing thorough the use of critical thinking to justify an answer is an essential component of mathematics education (Ahn et al., 2013). Chapter 3 included a description of the qualitative case study research design selected to examine mathematics teacher practices in writing through the use of critical thinking to justify an answer in a mathematics classroom.

Chapter 3: Research Method

Methodological fit is important when designing research. There are three methodological approaches for conducting research: quantitative, qualitative, and mixed methods. Quantitative research involves "testing objective theories by examining the relationship among variables' (Creswell, 2009, p.4). Quantitative methods involve the use of randomized groups, development of hypotheses, manipulation of an environment, and the collection of large numerical data that provide evidence of support for the study hypotheses (Creswell, 2009; Merriam, 2009). Qualitative research is focused on "exploring and understanding the meaning individuals or groups ascribe to a social or human problem" (Creswell, 2009, p.4). A qualitative approach is concerned with gaining an in-depth understanding of particular phenomena using textual data collection methods grounded in participants' real-life experiences in natural, uncontrolled settings (Creswell, 2009; Merriam, 2009). In a mixed-methods approach, both quantitative and qualitative methods are combined in specific ways to gain an in-depth understanding of a problem and/or phenomenon of interest (Creswell, 2009; Merriam, 2009).

In a quantitative design the researcher seeks to confirm hypotheses about a phenomenon. The purpose of a quantitative design is to quantify the data and generalize the results of the sample to the population of interest (Creswell, 2009). The sample is generally a large number of randomly selected participants that represent the population of interest. The data collection consists of numerical data such as questionnaires or surveys to predict causal relationships before and after an experimental treatment (Creswell, 2009). Unlike quantitative researchers who may employ a controlled experimental intervention with a randomly-selected sample of participants, a qualitative researcher seeks to explore a phenomenon as experienced by participants in their natural setting. The purpose of a qualitative design is to gain an understanding of the phenomenon being explored based on the perspectives of those experiencing the phenomenon (Creswell, 2009; Hatch, 2002). Generally speaking, a qualitative researcher collects evidence from a smaller pool of participants to develop deeper insights about how the phenomenon of interest is being experienced in the natural setting. Qualitative data collection consists of textual data generated from interviews or observations of participants to provide a complete and detailed description of the phenomenon being studied (Johnson & Christensen, 2008).

A qualitative research design was appropriate for this research because my aim was to gain an understanding of mathematics teachers' experiences of implementing the writing component of the GoMath mathematics literacy program in the natural setting of their classrooms. This approach allowed me, as the instrument of data collection (Creswell, 2009; Merriam, 2009), to observe firsthand the participants' classroom settings and instructional practices, and to gain an understanding of their perceptions about the mathematical literacy approach through one-on-one interviews (Hatch, 2002; Yin, 2014). This research design allowed for a rich textual description of mathematics teachers' practices in teaching critical thinking skills to provide written justifications of answers in general and special education mathematics classrooms (Hatch, 2002; Yin, 2014). Qualitative research also allowed me to make interpretations, based on the conceptual framework, about the study participants' perceptions and classroom instructional experiences. To analyze the data, I used open-coding procedures to identify categories of information, and axil-coding methods (Corbin & Strauss, 2008) to develop codes and subsequent themes (Boyatzis, 1998).

When identifying the appropriate qualitative research design for this study, I considered several options, which I discuss in the following section. In the next section, I address the issues of population and sample in case study research. Next, I discuss the rationale for the setting and sample, the measures for participants' rights, and my role as researcher. I then describe the qualitative data collection and analysis techniques that I used, and discuss my specific data analysis procedures. This chapter concludes with a discussion of validity, trustworthiness, and credibility.

Design of the Study

When designing this study, I considered three qualitative research designs: ethnography, phenomenology, and case study. Coming out of the disciplines of anthropology and sociology, ethnographic research involves a prolonged investigation of an intact cultural group in its natural setting in order to examine "shared patterns of behaviors, language, and actions" (Creswell, 2014, p.14). I did not select an ethnographic approach because the extended nature of field work was not practical for this type of doctoral research. The phenomenological research design comes from the disciplines of philosophy and psychology, and entails describing participants' lived experiences of a phenomenon. The goal of this approach is to "reduce individual experiences with a phenomenon to a description of the universal essence" (Creswell, 2009, p. 58). My aim in this study, however, was to understand teachers' instructional practices and perceptions about a particular mathematics literacy program, and was not to understand a particular cultural group, as in the case of ethnography, or describe the meanings teachers' ascribe to their lived experiences of the mathematics literacy program, as is the case in phenomenological research (Creswell, 2014; Moustakas, 1994). Therefore, case study design was the best qualitative approach for this study because the purpose was to describe the phenomenon of inquiry in its real-world context (Yin, 2014).

A case study is designed to gather data in a variety of ways, including but not limited to interviews, observations, audio and video data, and document collection (Stake, 1995). A case study adds depth, breadth, and validity to data collection through triangulation (Yin, 2014), and provides in-depth exploration of a specific program "bounded by time and activity" (Creswell, 2003, p. 15). The uniqueness of a case study is the ability to use different approaches to combining multiple sources. For example, an exploratory case study is research that looks for patterns in the data to develop hypotheses for future investigation. An explanatory case study seeks to explain why or how a certain behavior occurred by determining cause and effect (Yin, 2014), while a descriptive case study provides a rich description of the phenomenon being studied wherein information is collected without changing the environment (Yin, 2014).

To explore the teaching of critical thinking through writing to provide written justification of answer to mathematics problems, I used a qualitative case study of upper elementary and middle school mathematics teachers. Specifically, I sought to describe the mathematics teachers' practices in teaching writing within its real-world context in general and special education mathematics classrooms (Yin, 2014). This design allowed me to collect information from multiple sources and provide rich, thick descriptions of the teaching practices (Creswell, 2009; Yin, 2014).

Population and Sample Issues in Case Study Research

Yin (2014) argued that researchers should avoid using the terms *population* and *sample* when designing case study research. Even using the term "purposive sample" when referring to a case or cases is problematic in that doing so "risks misleading others into thinking that the case comes from some larger universe or population of like-cases, undesirably reigniting the specter of generalization" (Yin, 2014, p. 44). Rather, the best approach is to avoid referring to any type of sample and focus instead on describing the preferred rationale and criteria for selecting a case (Yin, 2014).

There are five primary rationales for single-case research designs (Yin, 2014). The first rationale for a single-case study is the need to select a *critical* case that would be essential to a particular theory or theoretical propositions. The second rationale involves selecting a case that represents an *extreme* or *unusual* case. The third rationale is what researchers refer to as the *common* case, the fourth rationale is the *revelatory* case, and the fifth rationale is the *longitudinal* case. The common case rationale applies to this study because "the objective is to capture the circumstances and conditions of an everyday situation…because of the lessons it might provide about the social processes related to some theoretical interest" (Yin, 2014, p. 52). Specifically, the phenomenon of interest was teachers' instructional practices and perceptions relative to the implementation of the writing component of the GoMath mathematics literacy program.

Setting and Sample

Setting and Population

The study took place at a small urban Title I public school in the northeastern region of the United States. The school ranges from prekindergarten to eighth grade, with approximately 620 students and 45 teachers. There are two fifth grade classes, including an integrated co-teaching class. There are three sixth grade classes, including two general education classes and an integrated co-teaching class. There are three seventh grade classes, including two general education classes and an integrated co-teaching class. There are four eighth grade classes, including two general education classes, an integrated co-teaching class, and a self-contained class. In the self-contained class there are three paraprofessionals who assist students with special needs. The student population is 31% Asian, 8% Black, 25% Hispanic, 36% White, and 1% American Indian. To gain access to the participants, I contacted the principal to explain the purpose of the research study and provided a letter of cooperation explaining the extent of the research study and process involved.

Sample Size and Characteristics

The unit of analysis for this descriptive case study was mathematics teachers who have taught the GoMath mathematics literacy program for two years in upper elementary and middle school general and special education classes at the Title I public school in the northeastern region of the United States. The mathematics teachers that I invited to participate in the study met two additional criteria: (a) they must be fifth- through eighth-grade mathematics teachers who have taught a minimum of three years; and (b) they must hold certifications in general education, special education, bilingual education, or mathematics. Of the school site's teachers who meet the selection criteria, three were general education mathematics teachers and one was a special education mathematics teacher. The special education mathematics teacher in the middle school teaches two different grade levels. All of the potential participants were knowledgeable of the GoMath math literacy program. Therefore, they provided information helpful for answering the study's research question.

Measures for Participants' Rights

After receiving approval form the Walden University Institutional Review Board (IRB) to conduct the study (09-17-15-0042358), I submitted a letter of cooperation to the principal of the selected school site (see Appendix A). Following Walden IRB and site approval, I submitted the Walden IRB and site approval documentations and my proposal to the northeastern region board for district approval. Upon school site and district approval, I inserted an information packet into a confidential sealed envelope and place the envelope in potential participants' school mailboxes. Included in the packet was a brief description of the study's purpose, an informed consent form, and a return envelope addressed to me. I informed teachers that my role as a researcher was separate from my work role as a mathematics teacher, that participation in this study was voluntary, and that the confidentiality of their participation and information was protected. Before beginning the study, I received signed informed consent forms from each of the teacher participants via my school mailbox. Data documents were protected in a locked file cabinet that is located in my home, and I am the only person who has the access code. A back-up data disk is also stored in the file cabinet. Electronic data were password protected on my personal computer, and I am the only person who has access to the password. I protected the teachers' identities by using pseudonyms (e.g. Participant 1) when reporting the findings. I was the sole data collector, and I did not share any data collected from the participants with teachers, administrators, or district personnel. After completion, I made the results of the study available to the administrators and staff. I also provided a two-page synopsis of the results to all stakeholders upon the completion of the study. All collected data will remain stored in a file cabinet and in password-protected file on my personal computer for at least five years after the conclusion of the study, and then I will destroy all data by deleting all relevant files from my computer and shredding documents and the backup disk (Creswell, 2003).

Role of the Researcher

For this qualitative case study, I am the researcher. According to Hatch (2002) and Janesick (2004), the qualitative researcher is the primary collector and analyzer of data. As recommended by Hatch (2002), it is essential that I described all roles I fulfilled in this study. I was responsible for recruiting the participants, obtaining all pertinent documents, conducting teacher interviews and classroom observations, and analyzing all results. The careful interpretation of the participants' responses was essential to the success of this study.

The participants knew me as a colleague and as a mathematics resource. I have been teaching at the local research site for 13 years. However, I hold no authoritative power over the teachers. Due to an existing collegial working relationship, trust, respect, and support exist between the potential participants and me. As noted by Rubin & Rubin (2005), when trust is the basis of a relationship, people begin to realize common interests among each other as professionals and as individuals. I acknowledged some biases might be present because I work at the site and because of my personal interest in mathematical literacy issues. According to Hatch (2002), researchers can keep track of any impressions, reactions, or reflections that are beyond the descriptions reserved for data collection. The study included bracketing to document any personal assumptions, interpretations, or hunches about emerging patterns. Additionally, member checking of interviews and analysis was used as means of identifying and addressing any bias issues.

Qualitative Data Collection Methods

According to Yin (2014), qualitative researchers should collect enough data so that there is confirmatory evidence (evidence from two or more different data collection sources) necessary for investigating the study's research questions. This qualitative case study involved investigating the following research question: How do fifth- through eighth grade mathematics and special education teachers use the GoMath literacy program to teach students to justify mathematics solutions in writing?

Data collection methods included two interviews (one pre-observation and one post-observation) and classroom observations with four mathematics teachers from fifth through eighth grades who have experience with the GoMath mathematics literacy program.

The qualitative data obtained through teacher interviews and classroom observations included the teachers' descriptions of how they implemented the writing component of the GoMath mathematics literacy program and their descriptions of how they guided their students to think critically about mathematics in the general and special education mathematics classrooms. The specific focus was to reveal the teachers' perceptions and practices relative to critical thinking, the GoMath mathematics literacy program, the importance of critical thinking in the mathematics literacy program, and the relevance of critical thinking in the mathematics curriculum.

Pre-Observation Teacher Interviews

Prior to collecting all data, I hosted an introductory meeting with all teacher participants before or after school and described the pre- and post-observation interview protocols and reviewed the interview questions (Appendix B and Appendix C) and assured the interviewees' confidentiality regarding their participation. I informed the interviewees that they had the right not to answer any of the interview questions. I informed the interviewees that there was a pre-interview prior to the classroom observation and a post interview following the observation. Interviews lasted 20 minutes and were audio recorded using a free digital recording program. Following the interviews, the digital recordings were forwarded to a transcriptionist who had previously signed a confidentiality agreement and two days later the participants received emails containing written transcripts.

When planning interviews, it was important to accommodate participants' schedules, availability, and need for convenient locations (Yin, 2014). Following the introductory teacher meeting, I discussed with each participant the interview times that best suited their schedules. The interviews were scheduled during non-instructional times and conducted via mutually convenient telephone conferences.

Before beginning each pre-observation interview, I ensured that I had received the participant signed informed consent form a week before the interview and agreed to an audio digital recording of the interview. Two interview sets of pre-observation open-ended interview questions had been developed: one for the general education mathematics teachers and one for the special education mathematics teacher (see Appendix B). These interview questions were developed for the purpose of answering research question one, focusing on general education mathematics teachers and special education mathematics teachers. The aim of the pre-observation interviews was to explore how the teachers described their practices when implementing the writing component of the GoMath mathematics literacy program. For the purposes of this study, it was helpful for me to hear the teachers' descriptions of their instructional practices prior to observing their actual implementation of practices in the classroom observation. In addition to audio recording the interviews to ensure data accuracy, I maintained journal field notes to document my observations and reflections during the first interview.

Teacher Classroom Observations

Yin (2014) maintained that a case study should take place in a real-world setting to understand the phenomenon being studied. Observations allow the researcher to view the phenomenon directly to gain insight into the world of the participants. The researcher may gain knowledge about additional information about the phenomenon from being in the setting that might have not been addressed during the interviews (Rubin & Rubin, 2005; Yin, 2014).

After the pre-observation interview, I scheduled a time with each participant to conduct a classroom observation at a time most convenient. The purpose of the observations was to provide a check and balance, and to confirm and minimize biased findings from the interview data (Yin, 2014). An observation protocol was used as outlined by Creswell (2009) and modified using the Danielson framework. The observation protocol contained six items guided my descriptive note taking and reflective note taking relative to the teachers' instructional practices (see Appendix D).

Prior to the observation, I sought the participants' permission to enter the classroom before the beginning of the mathematics lesson to prevent any distractions. During the observations, I sat at a table in the back of the classroom to prevent any distractions. The observations for each participant took place during the mathematics instruction period for a period of 50 minutes. This opportunity provided me with firsthand knowledge of what happens during the mathematics lesson and insights into the teachers' teaching practices (Yin, 2014).

Post-Observation Teacher Interviews

My aim for the second interview was to explore how the teachers described their experiences in guiding students' critical thinking about mathematics. For the purposes of this study, it was helpful for me to hear the teachers' descriptions of their experiences after I had observed their interactions with students in the classroom observation. In addition to audio recording the interviews to ensure data accuracy, I maintained journal field notes to document my observations and reflections during the second interviews. The journal notes helped me to extract correlations amongst the participants, analyze meaning from the participants' statements to see correlations to the conceptual frameworks, and to provide clarification of terms for the reader.

Data Analysis Procedures

Experts in qualitative research have suggested ways to process qualitative data so what has been discovered can be communicated to others (Hatch, 2002). Data should be organized and interrogated in such a way that will allow researchers to see patterns, discover relationships, develop explanations, and make interpretations about the phenomenon that was studied (Hatch, 2002; Yin, 2014). The data analysis began immediately following the data collection. Data analysis done simultaneously with data collection enables the researcher to focus and shape the study (Hatch, 2002; Yin, 2014). Hatch recommends (2002) beginning data analysis immediately following the data collection to help improve the quality of the research. Boyatzis's (1998) thematic analysis was used to analyze the datasets obtained from the pre- and post-observation interviews as well as the classroom observations.

Thematic analysis for qualitative research identifies, analyzes, and reports themes within the data (Boyatzis, 1998). Predetermined coding was performed during the data analysis phase, which is a deductive approach to analysis. Predetermined codes are used when the researcher wants to examine the data relative to the study's conceptual framework, particular problem areas, and/or key variables significant to the study (Miles, Huberman, & Saldana, 2014). The codes used for this study were based on my analysis of the data relative to the conceptual framework, specifically characteristics of critical thinking in mathematics: individual learning (LD), validation (V), reasoning (R), and deeper mathematical understanding (DMU).

Specific to this study, I worked with three datasets (pre-observation interviews, classroom observations, and post-observation interviews) to identify and label emergent codes, categories, and themes relevant to the mathematics teachers' practices, experiences, and perceptions about the implementation of the writing component of the GoMath mathematics literacy program and students' critical thinking about mathematics in both a general and special education mathematics classroom setting.

The first step in data analysis is to prepare the data. After the pre- and post-observation interviews and classroom observations were transcribed into Microsoft Word documents, I read through all of the data in order to gain a general sense of the information and reflect on its overall meaning (Creswell, 2003). The next step involved open-coding whereby I created a Microsoft Word table for each dataset (pre- and post-observation interviews and classroom observation) containing a column for the raw data and numerous columns for labeling/tracking emergent codes. I moved line-by-line through the raw data while conducting the coding phase of the analysis. Boyatzis (1998) explained that themes can be generated inductively from the raw data or deductively based on existing theory and prior research. In this case, themes were based on my analysis of the data relative to the conceptual framework, specifically characteristics of critical thinking in mathematics: individual learning (LD), validation (V), reasoning (R), and deeper mathematical understanding (DMU). Throughout the coding phase of analysis, I immersed myself in the data, reading and rereading, defining and refining codes, categories, and emergent themes (Rubin & Rubin, 2005).

Validity, Trustworthiness, and Credibility

Validity is an important aspect in the midst of data collection to ensure trustworthiness of the research (Hatch, 2002; Yin, 2014). Trustworthiness enhances the reader's confidence in the quality of the findings. Yin (2014) concurs that case studies should use triangulation procedures to promote validity of a study. Use of evidence from multiple sources can increase the confidence that a case study has depicted the event accurately (Yin, 2014).

To ensure credibility within data findings, it was helpful to consult experts in the area of the research to check or provide guidance on data collection tools (Yin, 2014). I consulted mathematics educators to ensure the validity and reliability of the context and specific meanings of the words used in the interview questions are not ambiguous, are culturally appropriate, and enabled me to answer the research questions and solve the problem framed. The teaching experiences of the mathematics educators consulted included those who were current or former staff developers and those who were current or former questionnaire writers for the school or district. The years of teaching experience ranged from 3 to 12 years. The mathematics educators agreed that the interview questions were in alignment with the research questions, were not ambiguous, were not biased or persuasive, and were consistent with standard English.

To determine the accuracy of the study's qualitative results, I implemented transcript review, which was a review of the transcribed audio recordings the interviews.

I conducted a 15-minute telephone conference with the participants to review the transcripts and ensured the interviews were recorded and transcribed properly. The transcripts were transcribed verbatim (Carlson, 2010). I also implemented member checking of the interviews, analysis, and the findings of the study to ensure my interpretations of the participants' data were accurate (Creswell, 2009; Hatch, 2002). Member checking was a vital strategy for establishing verification and credibility of the data findings (Hatch, 2002). Member checking provided the participants the opportunity to elaborate on the points of interest and to clarify any misconceptions from the data analysis (Carlson, 2010; Hatch, 2002). I offered a two-page summary of the study results to the participants to verify analysis and findings.

After I analyzed the interview transcripts, I summarized each participant's responses to each interview questions to look for themes that addressed the research question (Boyatzis, 1998). Upon the completion of the draft data analysis, I emailed the participants a copy of the draft data analysis to provide feedback on the interpretations of the data. I conducted a 15-minute telephone conference with the participants to discuss the interpretations and provide the participants the opportunity to clarify the interpretations and add any new or additional perspectives to support the study. If necessary, amendments were made.

A major strength of data collection in a case study is the opportunity to use multiple resources (Yin, 2014). Triangulation in a case study is likely to enhance data credibility when based on multiple resources of information to help support the findings of the study (Yin, 2014). The data from teacher interviews and observations were used to ensure the data findings were accurate and reliable (Hatch, 2002; Rubin & Rubin, 2005).

Chapter 4: Results

The purpose of this qualitative case study was to explore how fifth- through eighth-grade mathematics teachers use the GoMath mathematics literacy program to teach students critical thinking skills to help them provide written justification for their answers in a mathematics classroom. In particular, I aimed to understand how critical thinking in mathematics impacts students' mathematical reasoning and the justifications they give for their answers. One research question guided the study: "How do fifth- through eighth-grade mathematics teachers use the GoMath to teach critical thinking through writing?"

The chapter is organized according to the standards outlined in the Walden University qualitative checklist. In what follows, I present the results of this study according to the emerging themes, and align with current literature and critical thinking in mathematics. Next, I offer evidence of the trustworthiness of this study, and conclude with a summary of the findings and their relevance to the problem.

Data Generation, Gathering, and Recording

Following IRB approval (approval #09-17-15-0042358) and district approval from this study, I collected data between November and December 2015 using open-ended interviews and teacher observation with four participants. I had proposed using six participants, but two of them declined my request. All interviews were scheduled at a time that best suited the participants' schedules, took place via a telephone conference before or after school, and were audio-recorded with permission from each participant. I interviewed each participant before and again after observing them. I conducted the pre-observation interviews to determine how the participants used the GoMath mathematics literacy program to teach critical thinking through writing. A week before each interview was conducted, I provided the participant a copy of the interview guides (Appendices C and D) in a confidential sealed envelope in their school mailbox. All signed consent forms (Appendix B) were placed in the provided confidential sealed envelope and returned to my school mailbox. If the signed consent form was not returned in the confidential sealed envelope, I provided the form to the participant at the scheduled interview and had the participant sign the form prior to conducting the interview. I received signed consent forms from each of the four participants.

I observed participants in their classrooms during times that were convenient to their schedules. During the teacher observations, I sought to learn what strategies and activities teachers used to teach critical thinking through writing during mathematics instruction. I used an observation protocol (Appendix E) to provide detailed descriptive and reflective notes regarding the instructional practices recorded during each 45-minute observation. Subsquently, I used these reflective notes to verify how and the extent to which the participants' descriptions of their teaching practices aligned with what I observed. I also used the reflective notes to guide the post-observation interview by asking probing questions to seek clarification regarding certain aspects of the observation.

Following each observation, I scheduled a post-observation interview. The post-observation interviews were conducted to confirm how the participants used GoMath during mathematics instruction for critical thinking through writing. After pre- and post-interviews, I forwarded the digital recordings to a transcriptionist who had previously signed a confidentiality agreement, and two days later the participants received emails containing written transcripts to verify that what they intended to say was reflected in the transcription. I gave the participants two days to respond by noting any changes they wanted to make to the transcripts.

Once transcripts were verified, I began coding the data using four predetermined codes: reasoning, validation, deeper mathematical understanding, and individual learning. Reasoning was operationally defined as the way individuals form conclusions or inferences (Burns, 2012; Keiser, 2012). Validation refered to exposure to various methods students might not have thought of or recognized, which helps the students walk away with a more profound mathematical understanding (Larson et al., 2012). Mathematical understanding was defined as an understanding why something has occurred as opposed to only understanding what has occurred to better analyze a mathematical problem (Rondamb, 2014). Lastly, individual learning was defined as the ability to recognize the reasoning behind why mathematical concepts and formulas work (Rondamb, 2014) to help provide an opportunity to explore the connection between prior knowledge and current knowledge being constructed (Bruner, 1966; Keiser, 2012).

I entered the coded data into spreadsheets by participant and the predetermined codes. For example, the coded data for Participant 1 were entered on a spreadsheet titled Participant 1. Under Participant 1, I listed each predetermined code and entered any data pertaining to that code. For example, if Participant 1 referred individual learning, I labeled the spreadsheet with IL. Validation was labeled V, reason was labeled R, and deeper mathematical understanding was labeled DMU. I repeated this process for each participant.

Keeping Track of the Data

I stored all coded data in a spreadsheet for easy retrieval and kept them in a file cabinet and in password-protected file on my personal computer that is located in my home. The audio recorded interviews were downloaded to my personal password-protected computer.

Data Analysis

I used thematic analysis to analyze the datasets obtained from the pre- and post-observation interviews and the classroom observations. The purpose of thematic analysis is to identify, analyze, and report themes within the data (Boyatzis, 1998). To begin the analysis process, I read and reread each transcript to gain a general sense of the information and reflect on its overall meaning (Creswell, 2003). I began by analyzing the pre-observation interviews, then moved to the observations, and finished with the post-observation interviews, coding the data from each using the predetermined codes (IL, V, R, and DMU). I moved line-by-line through the raw data while conducting the coding phase of the analysis. I used a reflective journal to record any patterns noted in the participants' responses. While conducting each pass through the data, I synthesized and then summarized the data for each participant, noting summaries in my journal. Once I completed this step for the four participants, I collectively summarized their responses, noting similarities, differences, and emergent categories which resulted in themes. During the analysis process, I reviewed the characteristics of critical thinking in mathematics reported in the current literature on this topic and made marginal comments in my reflective journal.

Findings

The findings are based on my overarching research question and the pre- and post-observation interviews and observations in four mathematics classrooms. In my analysis of these three data sets, two themes emerged: oral communication, and reasoning in critical thinking. In what follows, I present my findings by themes that evolved out of the data.

Theme 1: Oral Communication

The GoMath program is a student-centered interactive approach to teaching critical thinking through writing. Students are expected to record their strategies, explanations, and solutions for solving mathematics problems. Participants agree that these outcomes are valued and necessary for students to be independent learners in mathematics. To achieve these outcomes, every teacher encouraged students to engage in oral communication before writing. Participant 1 used student oral dictation as a means of recording student thinking in solving problems, noting, “I have my students explain it (solutions) to others. I know they are thinking critically if they explain it to others.” During the post-observation interview, Participant 1 encouraged students to draw a picture related to the problem while explaining the steps taken to solve the problem. Participant 2 used discussion in small groups, and believes that critical thinking through writing comes from communicating verbally. This participant noted, “I have the students use the explore activities in the GoMath. This is their opportunity to have a conversation with the other students to come up with what's the best way of justifying their reasoning." This point was mentioned in both the pre- and post-observation interviews. Participant 3 used the shared writing strategy as a part of the discussion process. This participant stated, "They're sharing ideas with one another which they later write down in their math answer." The written answer--and ultimately critical thinking--is contingent on the discussion that occurred during shared writing. Participant 4 did whole-group discussions in which the group members justified their thinking and explained steps they used to solve a mathematics problem. These students would copy the answer in their books that the teacher had written for them on the board.

Regardless of the grade, each teacher used whole group, small group, or student pairs to discuss and justify their answers prior to writing them. Collectively, these teachers believe that if students could verbally explain their reasons, they were thinking critically and were ready to transition their talk to the written form.

Theme 2: Reasoning in Critical Thinking

The main focus of GoMath is critical thinking through writing. Reasoning is a fundamental part of critical thinking. For fourth grade students early in the year, reasoning is difficult or not well developed. Participant 1 asserted,

> Most of our kids are not abstract thinkers yet. Piaget would say that they're still in the concrete stage until at least 12 and we are dealing with 9 and 10 year olds and having them make these abstract connections and thoughts and explain their writing in a formative way, it's a lot we're asking of them.

Participants 2 and 3 viewed reasoning from two perspectives – the student and the teacher. Students in their classes were expected to use inferences and draw conclusions. Questions were posed to elicit feedback regarding how students reasoned. For example, Participant 3 would ask,

> Do they go algebraically? Do they do guess and check? What do they use from prior knowledge? What evidence can they find to support their choice and answer questions? Why do they think this is one way or the other way?

Both participants believe that teachers need to understand critical thinking and students' mental processes. They realize that it is difficult to know students' processing simply through answers on a page. When students must explain how they arrived at the answer or solved a mathematics problem, it was obvious to the teachers that students were using critical thinking skills. Participant 3 believes that critical thinking can be transferred to other subject areas and other aspects of life.

Participant 4 taught reasoning by example. Students were not expected to reason, but followed the teacher's work sample on the board. Students had difficulty with the mathematics terms, so Participant 4 reworded the problems or simplified the language to allow students to understand the concept taught in a different way. The students in this class completed more computation problems than word problems. Regardless of the mathematical prompt, Participant 4 did use oral communication to test understanding and reasoning.

All teachers used reasoning in critical thinking, some to a greater degree than others. Each of them valued critical thinking and taught it to the level of understanding of the students. Once again, verbalization of the thinking process was evident in the pre- and post-interviews and the observations.

Discrepant Data

There were no discrepant data in this study. All participants responded to the prompts as presented, and shared their approaches to teaching critical thinking through writing in their interviews and observations.

Evidence of Quality

I used transcript reviews to assure the quality of the data. I hand delivered participants' transcripts and requested that they check their interviews for accuracy. Using transcript review reduces the validity of the findings because the raw data only reflect participants' words and not the analyzed findings. Additionally, the transcripts (participants' words) are not supported by current literature or the conceptual framework; thus, reducing the soundness of the study.

I implemented member checking of the interviews, analysis, and findings of the study to confirm my interpretation of the participants' data (Creswell, 2009; Hatch, 2002). Member checking is a vital strategy for verification and for establishing credibility of the findings (Hatch, 2002). Member checking provides the participants the opportunity to elaborate on the points of interest, and to clarify any misconceptions from the data analysis (Carlson, 2010; Hatch, 2002). I have prepared a two page summary of the study to share with the participants so that they can verify the analysis and findings from the study.

Limitations

The study's findings are limited due to the small sample size and lack of depth of the data. With only four participants, the findings are incomplete and only pertain to those who volunteered to participate. Data could have been strengthened by using follow-up and probing questions throughout the pre- and post-observation interviews, and by linking the post-observation questions to the observation protocol.

Summary

Teachers in general education and special education mathematics classrooms taught writing as a mode of critical thinking that can be used to justify answers to mathematics problems. The teachers used the writing component of the GoMath mathematics literacy program to guide students to think critically when justifying their answers. The instructional practices teachers used included verbal communication, shared writing, peer feedback, critical thinking writing strategies, and teacher modifications. The common theme that consistently occurred in the interviews and teacher observations was the focus on verbal communication to help guide the students in writing critically to justify their answers. Writing was evident in the mathematics classrooms. However, the common concern that teachers consistently noted in the interviews was a lack of professional development regarding the teaching of critical thinking through writing in mathematics. In the remaining chapter of this study, I discuss the conclusions and make recommendations for further research drawn from the data analysis.

Chapter 5: Discussion, Conclusions, and Recommendations

The low test scores of students at my study site serve as evidence of the need to improve their mathematical literacy. The results from the Trends in International Mathematics and Science Study (TIMSS, 2007, 2011) included two overarching issues for mathematics educators with regard to developing or increasing critical thinking and mathematical understanding among students: the lack of verbal communication, and the lack of written communication needed to justify students' answers (Mullis et al., 2007; Mullis et al., 2011). Given this problem, the purpose of this qualitative case study was to explore how mathematics teachers used the GoMath literacy program to teach critical thinking through writing. In particular, I aimed to understand how critical thinking impacts students' mathematical reasoning and justification of their answers. Mathematics literacy pedagogy includes an emphasis on communicating mathematical ideas to provide students with the opportunity to think critically in order to sharpen their understanding of mathematical ideas (Barlow & Drake, 2008).

A qualitative case study design was appropriate for this research because my aim was to gain an understanding of mathematics teachers' experiences of implementing the writing component of the GoMath mathematics literacy program in the natural setting of their classrooms. This approach allowed me, as the instrument of data collection (Creswell, 2009; Merriam, 2009), to observe firsthand the participants' classroom setting and instructional practices as well as gain an understanding of their perceptions about the mathematical literacy approach through one-on-one interviews (Hatch, 2002; Yin, 2014). This research design allowed for a rich textual description of mathematics teachers' practices in writing through the use of critical thinking to justify an answer in general and special education mathematics classrooms (Hatch, 2002; Yin, 2014). Qualitative research also allowed me to make interpretations, based on the conceptual framework, about the study participants' perceptions and classroom instructional experiences while, analyzing data using open-coding procedures to identify categories of information and axial-coding methods (Corbin & Strauss, 2008) to develop codes then themes (Boyatzis, 1998). In summary, the analyses led to two noteworthy findings that were associated with two emergent themes that I discussed in the following section: (a) oral communication, and (b) reasoning in critical thinking.

Interpretation of Findings

This discussion of my interpretation of the findings includes three major sections. First, I present conclusions that are bounded by evidence in order to address the study's guiding research question. Next, I relate the findings to the research literature. Lastly, I discuss practical applications of the findings relevant to the study's research site.

Conclusions

The conclusions I have drawn from the findings are all linked to the study's guiding research question: "How do fifth-grade through eighth-grade mathematics teachers use the GoMath literacy program to teach students to justify mathematics solutions in writing?" During my analysis of classroom observations and pre- and post-observation interviews, two themes emerged: oral communication, and reasoning in critical thinking. Study participants discussed how oral communication provided students the opportunity to think critically when explaining and justifying their mathematical reasoning. The participants believed oral communication helped the students transition their thoughts into written form. All teachers who participated in this study encouraged students to engage in oral communication before writing. Moreover, verbal communication of the thinking process was a repeated theme in the pre- and post-observation interviews and in the classroom observations, which shows the relationship of this first theme to the second theme of reasoning in critical thinking. All teacher participants used reasoning in critical thinking; some to a greater degree than others. Each teacher valued critical thinking and taught it at the students' level of understanding.

Relationship of Findings to the Literature

The research literature specific to this study's conceptual framework indicates that writing in mathematics has an overall positive impact on student learning. The use of writing in mathematics is effective for promoting discovery and developing critical thinking skills while developing mathematical understanding (Ahn et al., 2013; Steele, 2007). The connection between critical thinking and mathematical understanding is evident in research, indicating that learning extends beyond the reproduction of information (Sandmel & Graham, 2011) to include students' active knowledge construction (Boscolo & Mason, 2001). Positive outcomes of this connection are that students can become less dependent on teachers and take more responsibility for validating their own mathematical thinking (Keiser, 2012; Rasmussen & Marrongelle, 2006). Moreover, students who are taught how to reason and think critically through writing significantly outperform students who are taught using the traditional lecture method in measures of mathematical achievement and problem solving (Zakaria, 2007).

Roskin (2010) reported that when writing was used as an instructional strategy in mathematics, a significant improvement was found among fifth-grade students' reasoning. Similarly, Bettencourt (2009) found improvement, from pretest to posttest, in the reasoning of an experimental group of eighth grade students' who received writing as an instructional strategy for mathematical understanding. However, although the experimental and control groups showed improvement, the results of the study did not show a significant difference in mathematical understanding and achievement between the two groups.

The literature specific to oral communications and mathematical instruction (Keiser, 2012; Roake & Varlas, 2013) is in keeping with my findings. Students' learning and ability to build mathematical meaning is supported by oral and written communication (Burns, 2012; Hintz, 2014; Keiser, 2012). For example, Burns (2012) investigated how mental computation skills and verbal communication were related to the Common Core state standards. She found that when fifth-grade and sixth-grade students were asked to verbally describe how they facilitated mental computations to solve a particular math problem, they were able to provide a viable argument for how they solved the problem using specific structures, while demonstrating precision in tasks. Moreover, Keiser (2012) found that middle-grade teachers who facilitated in-class discussions based on students' correct and incorrect strategies reported increased accuracy and efficiency in students' calculations. Roake and Varlas (2013) maintained that students need to articulate their reasoning behind solutions to mathematical problems in order to help develop skills of synthesis and integration. For Roakes and Varlas, synthesis and integration skills are critical components of cognitive development and are evident when students take the time necessary to process their mathematical thinking (instead of merely performing rote procedures), mentally construct how they will orally communicate their thoughts, articulate their thoughts, and reflect on their mathematical thinking based on feedback from peers, teachers, and observations of other students' solutions. The NCTM (2014) reported that embedding verbal communication in the mathematics curriculum helps students become critical thinkers by constructing focused meaning of a topic rather than examining a given rule or procedure. Working with sixth- through eighth grade students, Keiser (2012) found that incorrect answers produced rich and meaningful discussions among students. The discussions provided students with the opportunity to reflect on their reasoning and examine relationships between different mathematical approaches to solving problems. These oral communications helped foster a greater mathematical understanding of topics and build students' confidence in problem-solving and application of mathematical skills (Keiser, 2012).

My findings were also consistent with the literature on reasoning and critical thinking in mathematical instruction. The teacher participants' instructional practices evidenced their belief in the value of reasoning in critical thinking. Research indicates that when students understand the reasoning behind mathematical concepts, which can occur through writing (Rothman, 2012; Soares et al., 2012), they are able to extend learning beyond abstract formulas and procedures to make connections to real-world applications (Ahn et al., 2013).

Practical Application of Findings

The findings from my study have practical application to the research site, an urban Title I public school. Because students enrolled in this school were performing poorly on the short and extended constructed response questions on the state exam, administrators implemented the GoMath literacy program as a means of improving students' critical thinking in mathematics. Specifically, the school's scores on the writing component of the mathematics were reported at a level 1, which is below state standards, and a level 2, which is approaching state standards. Findings from the study indicate that participating teachers perceived the GoMath literacy program as having a positive influence on the development of students' oral communications and reasoning in critical thinking skills. These findings are consistent with Burns's (2012) research that related verbal communication of reasoning in critical thinking skills to the attainment of Common Core state standards for mathematics. School leaders should apply these findings to the administration of the GoMath program and related teacher professional development to further efforts to improve students' performance on the state standards for mathematics.

Limitations of the Study

The findings from the study are limited due to the small sample size and lack of depth of the data. I had originally recruited six participants, but two of them declined participation. With only four participants in the study, the findings are incomplete and only pertain to those who volunteered. I could have strengthened the data by using follow-up and probing questions throughout the pre- and post-observation interviews, and by linking the post-observation questions to the observation protocol.

Implications for Social Change

When considering implications for social change, I addressed four questions: (a) What is the change? (b) Who provides the change? (c) What are the benefits and who benefits from the change? and (d) How does the change apply to the problem?

What is the Change?

Because of the small sample size, the potential impact of this study for positive social change is limited to the individual and organizational levels. The specific change is threefold. The first change is the expansion of mathematics instructional practices to include oral communication and reasoning in critical thinking in classroom activities. Second, students' mathematical abilities are positively impacted as a result of this expanded instruction. The third change involves schools' improved performance on the statewide standardized mathematics exams.

Who Provides the Change?

The changes in mathematical instructional practices, students' mathematical abilities, and schools' improved performance on state standardized exams are brought about by teachers and school administrators. Teachers provide the change by utilizing the GoMath literacy program in the classroom as a means of improving students' oral communications and reasoning in critical thinking. School administrators provide change by supporting teachers' efforts with effective professional development specific to the use of the GoMath literacy program.

What are the Benefits and Who Benefits from the Change?

The small sample size limits the potential impact of this study for positive social change to the individual and organizational levels. First, findings from this study have minimal implications for individual fifth-grade through eighth-grade teachers and their students. The study participants agreed that for students to become independent learners in mathematics, they should be able to think critically when recording strategies, explanations, and solutions necessary for solving mathematical problems. All teacher participants stressed the importance of students engaging in oral communications before performing critical thinking through writing assignments. This finding has implications for the teachers and students at the research site who are required to participate in the GoMath curriculum. Instructional time should be planned to allow for large and small group discussion.

Second, study findings have implications at the organizational level for the school research site. Although the participants valued critical thinking and taught it in their classrooms, both general education teachers and the special education teacher described how the lack of professional development opportunities for critical thinking in writing in mathematics hindered their classroom practice. The administrators of the research site, a small school, could consider partnerships with other schools within the district to expand professional development, which could benefit their teachers' classroom practice.

Furthermore, at the organizational level, educational policies and curriculum must foster rich mathematical knowledge to all students from prekindergarten to grade 12 by providing them with the opportunity to explore critical thinking in writing in mathematical ideas to help deepen their understanding of these ideas and make mathematical connections within and outside mathematics (Fennema, Sowder, & Carpenter, 1999). For the successful implementation of critical thinking in writing in mathematics, the entire school community must be involved in helping students gain mathematical understanding. The community can consist of general and special education mathematics teachers, administrators, parents, math and literacy coaches, and regional and instructional math and literacy superintendents. To bring forth this organizational-level social change, the community should have frequent interactions to communicate similar mathematical goals and objectives (Lambert et al., 2002) for effectively implementing critical thinking in writing in mathematics. Efficacy will be developed by the community working together to create mission and vision statements which will state the community's purpose and coherent action for implementing social change within the mathematics education (Lambert et al., p.181). As a result, all members of the community will know their input is valued and respected in bringing forth a positive social change.

How Does the Change Apply to the Problem?

The problem investigated in this study was students' poor performance on constructed response questions on state standardized mathematics exams. Specifically, the study's research site, an urban Title I public school, was reporting scores on the writing component of the state mathematics exam at level 1, which is below state standards, and level 2, which is approaching state standards. In response, school administrators instituted the GoMath literacy program to address students' critical thinking in mathematics. By further utilizing the GoMath program in the classroom to improve students' oral communications and reasoning in critical thinking, mathematics teachers will provide the support needed to enhance their students' critical thinking abilities. By learning to justify their answers through oral and written communications, it is anticipated that students' academic success in both the general education and special education mathematics classrooms will improve. Furthermore, by supporting general education and special education teachers by expanding professional development specific to the utilization of the GoMath literacy program, school administrators can contribute to the school's scores on the state mathematics exam.

Recommendations for Action

The first recommendation involves professional development for general education mathematics teachers. A common concern among teachers, general education and special education, that was discussed during the study interviews was the lack of professional development received specific to critical thinking for writing in mathematics. Future research could compare two general education mathematics teacher groups relative to their attitudes and classroom practices with the writing component of the GoMath mathematics literacy program. The first group should be comprised of general education teachers who only participated in the initial training prior to the implementation of the GoMath program. The second group should include general education teachers who have participated in six or more additional professional trainings on how to effectively incorporate critical thinking through writing in the mathematics classroom.

The second recommendation is specific to professional development for special education teachers who provide additional support for their students' mathematical instruction. One special education teacher who participated in this study explained that she had not received any professional development for critical thinking in writing within mathematics. She discussed the unique problems of special education teachers who are not full-time mathematics teachers. In addition to not being subject matter experts in mathematics, special education teachers' schedules may prevent them from attending meetings and professional trainings planned to accommodate general education teachers' schedules. Moreover, special education teachers' professional development for critical thinking and writing in mathematics should be different from the general education teachers' professional development due to different student population they serve.

Recommendations for Future Research

This qualitative case study was conducted over a period of two months to investigate fifth-grade through eighth-grade mathematics teachers' practices when implementing the writing component of the GoMath mathematics literacy program. Specifically, the investigation focused on the critical thinking component of the GoMath program that requires students to justify their answers to math problems. Study participants included three general education mathematics teachers and one special education teacher. This section features three recommendations for future research.

This study explored how fifth-grade through eighth-grade general education mathematics teachers used the GoMath literacy program to teach students to justify mathematics solutions in writing. However, findings from this study suggest the need to investigate how special education mathematics teachers use the GoMath literacy program because it could be expected that modifications would need to be made in the GoMath program to accommodate the learning needs of this group of students. Additionally, although general education teachers described their practices in implementing the writing component of the GoMath program, future efforts should focus on determining which of these practices are most effective and which practices are least effective. Furthermore, study participants addressed the need to improve opportunities specific to the use of GoMath in order to support their instructional practices and accommodate their scheduling needs. School administrators and mathematics department leaders should pay particular attention to the findings from this study and consider these recommendations for action. The results of this study will be disseminated through the publication of the dissertation. The researcher is considering preparing an executive summary of the results for sharing with administrators and mathematics teachers at the research site.

A third recommendation is to replicate this study with a larger sample of general education teachers and/or special education teachers. Rather than using a cross-sectional design that entails collecting data from study participants at one point in time, a longitudinal design should be used. The benefits of a longitudinal study include the ability to follow study participants over the course of months or years relative to the phenomenon of inquiry. In the case of professional development for critical thinking and writing in mathematics, it would be beneficial to understand how general education teachers and/or special education teachers' classroom practice is impacted by expanded trainings and determine if the expanded professional development impacts student success in critical thinking and reasoning in mathematics.

Summary

This qualitative case study is important because it provides a description of fifth-grade through eighth-grade mathematics teachers' classroom practices for implementing the writing component of the GoMath mathematics literacy program. Of particular note are this study's findings about how general education teachers and a special education teacher perceive student instruction focused on critical thinking to justify an answer in the mathematics classroom. This summary includes my reflections as the researcher followed by concluding statements.

As the study researcher, this investigative process has caused me to reevaluate my journey as a middle-school mathematics teacher. I use the GoMath mathematics literacy program in my classroom and, from my perspective, the program focuses on critical thinking through the use of writing within the lessons. During this study, I appreciated the participants' honesty and candid comments. I noticed the participants did not hold back in expressing themselves in the interviews. I realized that critical thinking through the use of writing was not a focus of the special education participant who uses the GoMath program. I learned through the interviews that this participant expressed a lack of professional development in critical thinking and writing in a mathematics classroom due to her population being students with learning disabilities. In addition, throughout the interview, the participant had difficulty answering the questions due to not knowing how to properly help guide her students in critical thinking through the use of writing in mathematics.

Despite the research site being a small school, I realized all of the teachers do not reach out to each other for support. I became aware of a contrast amongst the participants in regards to receiving professional development and having a familiarity with how their colleagues are implementing critical thinking through the use of writing in mathematics. Two geneal education participants (P2 and P3) reported having received some professional development, but they explained that ongoing professional development would contribute to their continual improvement as teachers. In contrast, one general education participant (P1) and the special education participant (P4) described a lack of professional development and expressed the need for professional development in the use of GoMath. General education participants two and three described awareness of how their colleagues are implementing critical thinking through the use of writing in mathematics and reported having frequent conversations to learn from each other. In contrast, the other general education (P1) and the special education participant (P4) reported a lack of awareness of how their colleagues are implementing critical thinking through the use of writing in mathematics. Participant 1 described herself as being self-absorbed and not paying attention to the colleagues in her school. She further expressed how her participation in this study brought to light some of her short-comings.

I have always been aware of the lack of professional development and support for special education teachers, not only in mathematics but in all subject areas. Since I am a general education mathematics teachers who also works with at least one special education teacher every year, I have reflected on my professional developments and have realized the professional developments I have attended were mainly geared toward general education teachers with little regard to how we can support our special education co-teachers. I plan to continue to request at the school level and district level separate mathematics professional developments for special education teachers, joint mathematics professional developments for general education and special education teachers who co-teach together, and weekly collaboration time. The administration at the school and district level should be made aware that special education teachers are seeking separate professional development opportunities as well as collaborative professional development opportunities with their general education co-teacher. Sufficient professional development and collaboration time will help increase teacher pedagogy and help bridge the gap in critical thinking and writing in mathematics. This will also help provide teachers with the necessary knowledge and best teaching practices to tailor their instruction to meet the needs of every single learner in their classrooms. This study has been a great asset in helping me continue to improve, not only as an educator, but in my efforts to help my colleagues improve as educators and to help the students in my school community improve in their critical thinking and writing skills in mathematics.

In conclusion, writing is central to the understanding process in any content area. The use of critical thinking in writing in mathematics helps students explore different ways of solving a problem while improving their abilities to communicate their mathematical thinking. When students think critically, their mathematical understanding is being built, their mmathematical vocabulary expands, and their writing improves relative to expressing their mathematical thinking. Critical thinking in writing in mathematics is an important mathematical communication skill, both verbal and written, and it provides students with the opportunity to express their thinking as well as sharpen their understanding. Mathematics education must create a link between critical thinking, mathematics, and language in order to help students think critically and communicate their mathematical thinking in writing.

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Appendix A

Informed Consent: Participant 18 years of Age and Older

Dear Teacher Participant,

My name is Angelique E. Brown and I am a student at Walden University working towards my Doctorate of Education (Ed. D.). Since I am a mathematics teacher at the school, my role as a researcher is separate from my work role. The intent of this letter is to inform you of my research intent and to request your participation in it. You were chosen for the study because you have at least three to eight years teaching mathematics and a pioneer in the implementation of the mathematics GoMath literacy program in December 2013. Please read this form and ask any questions you have before agreeing to be part of the study.

Background Information:
The intent of my qualitative research is to examine teacher practices in writing through the use of critical thinking to justify an answer in general and special education mathematics classrooms.

Procedures:
If you agree to be in this study, you will be asked to:

- Participate in a 45 minute pre and post-interview via a telephone conference that will be audio recorded.
- Participate in a 50 minute classroom observation throughout the study.
- Participate in a 15 minute transcript review via a telephone conference to verify audio recorded interview was transcribed properly. Transcripts will be emailed.
- Participate in a 15 minute member checking via a telephone conference to review the data collected and findings of the study by the researcher for further clarification and additional information. Data analysis and findings will be emailed.
- Following the pre-observation interview, we will schedule a convenient time for the classroom observation.
- A 2-page synopsis of the result will be provided to you upon completion of the study.

Voluntary Nature of the Study:
Since I am a mathematics teacher at the school, my role as a researcher is separate from my work role. Your participation in this study is strictly voluntary. Your decision whether or not to participate will not affect your current or future relations with the researcher and the upper elementary and middle school. If you initially decide to participate, you are still free to withdraw at any time later without affecting those relationships.

Risks and Benefits of Being in the Study:
There are no risks associated with participating in this study and there are no short or long-term benefits to participate in this study. In the event you experience stress or anxiety during your participation in the study you may terminate your participation at any time. You may refuse to answer any questions you consider invasive or stressful. This may help teachers in this school and similar schools receive effective professional development opportunities for implementing critical thinking to justify answers in mathematics classrooms in order to enhance students' problem solving abilities as critical thinkers.

Compensation:
There will be no compensation provided for your participation in the study.

Confidentiality:
The records of this study will be kept private. In any report of this study that might be published, the researcher will not include any information that will make it possible to identify you. Research records will be kept in a locked file, and only the researcher will have access to the records.

Contacts and Questions:
The researcher conducting this study is Angelique E Brown. The researcher's faculty chair advisor is Dr. Jerita Whaley, PhD. You may ask any questions you have now. If you have any general questions later, you may contact the researcher at angelique.brown@waldenu.edu or the chair at jerita.whaley@waldenu.edu. If you want to talk privately about your rights as a participant, you can contact the university's Research Participant Advocate at irb@waldenu.edu or 612-312-1210. Walden University's approval number for this study is 09-17-15-0042358 and it expires September 16, 2016.

Statement of Consent:
I have read the above information. I have asked any questions and received answers. I consent to participate in the study. The researcher will give you a copy of this form to keep.

Printed Name of Participant___________________________ Date_______________

Participant Signature_________________________________ Date_______________

Signature of Research Investigator_____________________ Date_______________

Appendix B

Pre-Observation Interview Guide

Date:

Time:

Place: P.S./M.S. _____

Interviewer: Angelique E. Brown

Interviewee: Mr/Mrs. _____

Opening Comments by Interviewer

- A welcome statement will be given and I will thank the interviewee for his/her participation: Good Morning Mr/Ms. _____! Thank you for taking the time to complete this interview. Your participation on this educational project on mathematical literacy in the mathematics classrooms is important in improving critical thinking. It will help teachers learn how to guide students to think critically and to help students build upon their mathematical reasoning. Ultimately, the goal is to help increase student learning and achievement in mathematics.
- Your participation is voluntary and at any time there is a question you do not want to answer just let me know.
- I will remind the interviewee that the interview will be taped and the interviewee will receive an emailed copy of the transcripts and have the opportunity to look over the transcripts for accuracy to ensure that I have captured what the

interviewee really wants to say. The interviewee will have the right to make any corrections or additions.

- I will take notes during the interview.
- I will explain to the interviewee that his/her name will not be used in the transcripts to ensure confidentiality. I will explain to the interviewee that no one at the school will see nor have access to the audio, notes, and transcripts of the interview.
- As you know we set aside 45 minutes for the interview, is that still okay with you? We will not go past 45 minutes unless you would like to do so. Audio taping is still okay with you?
- Do you have any questions before we start the interview?
- At the conclusion of the interview, I will once again thank the interviewee for his/her participation.

Pre-Observation Interviews: General Education Teachers

Research Question #1: How do fifth-grade through eighth-grade general education math teachers describe their practices as they implement the writing component of the GoMath mathematics literacy program?

1. How long have you been teaching the GoMath program? How did the students respond to the GoMath program?
2. How do you plan and teach the GoMath writing component? Provide an example of how you implement the writing component. How often do you have your students write?

3. What writing strategies do you implement when students use critical thinking to justify their reasoning? What strategy modifications are implemented if any?
4. Describe what type of instrument you use to review students' critical thinking to justify their reasoning. Describe when you use the instrument. For example, small group, whole class, or individual.
5. How do you convey the importance of communicating in writing in mathematics to your students? How do you encourage reluctant students to write their justifications?
6. How do you use shared writing to teach students to think critically when justifying their reasoning? How do you know when students have thought critically when justifying their answers?
7. What strategies do you use to encourage students to share their writing with each other in class? Describe the students' reactions in sharing their writing with others.
8. How do your students' written responses help you to plan or modify your instruction? Describe your planning or modification process.
9. What professional development have you had in teaching critical thinking in writing in mathematics? What faculty support is available after receiving professional development?
10. What areas of the writing component do you need additional support? How will this support help improve your instruction?
11. How do you bridge the gap in critical thinking and writing in mathematics? Why is this important for teachers and students?
12. What else would you like to add?

Pre-Observation Interviews: Special Education Teachers

Guiding Research Question #2: How do fifth-grade through eighth-grade special education teachers describe their practices as they implement the writing component of the GoMath mathematics literacy program?

Interview Questions

1. How long have you been teaching the GoMath program? How did the students respond to the GoMath program?
2. What is the structure of the GoMath writing component? Provide an example how you provide additional support for implementing the writing component. How often do you have your students write?
3. How do you modify your instruction for struggling students when they are required to think critically to justify their answers? Describe the type of strategy modification you use?
4. What type of accommodations do you implement for struggling students when they are required to use critical thinking to justify their reasoning? Why did you choose these accommodations to help those students?
5. Describe what type of instrument you use to review students' critical thinking to justify their answers. Describe when you use the instrument. For example, small group, whole class, or individual.
6. How do you convey the importance of communicating in writing in mathematics to your struggling students? How do encourage any reluctant student to write their justification?

7. How do you use shared writing to teach students to think critically when justifying their reasoning? Describe the students' reactions in sharing their writing with others.
8. What strategies do you use to encourage your struggling students to share their writing with each other in class? Describe how you get a reluctant student to share his/her writing with others.
9. How do your students' written responses help you plan or modify your instruction for struggling students? Describe your planning or modification process for struggling students?
10. What professional development have you had in teaching critical thinking in writing in mathematics for struggling students? What additional support is provided after receiving professional development?
11. What areas of the writing component do you need additional support? How will this help your instruction with any struggling student?
12. How do you bridge the gap in critical thinking and writing in mathematics for struggling math students? How will this help struggling students?
13. What else would you like to add?

Appendix C

Post-Observation Interview Guide

Date:

Time:

Place: P.S./M.S. _____

Interviewer: Angelique E. Brown

Interviewee: Mr/Mrs. _____

Opening Comments by Interviewer

- A welcome statement will be given and I will thank the interviewee for his/her participation: Good Morning Mr/Ms. _____! Thank you for taking the time to complete this 2nd and final interview in the research process. Your participation on this educational project on mathematical literacy in the mathematics classrooms is important in improving critical thinking. It will help teachers learn how to guide students to think critically and to help students build upon their mathematical reasoning. Ultimately, the goal is to help increase student learning and achievement in mathematics.
- Your participation is voluntary and at any time there is a question you do not want to answer just let me know.
- I will remind the interviewee that the interview will be taped and the interviewee will receive an emailed copy of the transcripts and have the opportunity to look over the transcripts for accuracy to ensure that I have captured the interviewee

really wants to say. The interviewee will have the right to make any corrections or additions.

- I will take notes during the interview.
- I will explain to the interviewee that his/her name will not be used in the transcripts to ensure confidentiality. I will explain to the interviewee that no one at the school will see nor have access to the audio, notes, and transcripts of the interview.
- As you know we set aside 45 minutes for the interview, is that still okay with you? We will not go past 45 minutes unless you would like to do so. Audio taping is still okay with you?
- Do you have any questions before we start the interview?
- At the conclusion of the interview, I will once again thank the interviewee for his/her participation.

Post-Observation Interviews: General Education Teachers

Guiding Research Question #3: How do fifth-grade through eighth-grade math teachers describe their practices in guiding students to think critically about mathematics in general and special education classrooms?

Interview Questions:

1. Tell me about the writing component of the lesson I observed?
2. What part of the writing component was effective in teaching the math lesson? What did you find was the least effective?
3. What challenges, if any, did you encounter during the writing component? Describe how you modified the lesson to address students' needs.

4. What part of the writing component would you change? How would you teach it differently?
5. What changes did you observe in your student's critical thinking skills when they were required to justify their reasoning in writing? What were common errors students made in their reasoning in writing? What were the strengths students demonstrated in their reasoning in writing?
6. What benefits do you think the students gained when sharing their writing with each other? How has student sharing impacted the learning environment in your classroom?
7. What trends in the writing component for GoMath do you notice are evident in your school? How do you think other teachers are implementing the writing component in math lessons?
8. What trends do you think are not evident? What do you think are some possible reasons?
9. What support do you need to enhance critical thinking in the writing instruction in your classroom? How often would you like the support?
10. What else would you like to add?

Post-Observation Interviews: Special Education Teachers

Guiding Research Question #3: How do fifth-grade through eighth-grade math teachers describe their practices in guiding students to think critically about mathematics in general and special education classrooms?

Interview Questions

1. Tell me about the lesson I observed?
2. What part of the writing component from the lesson worked well? Which part needs improvement?
3. What writing strategies did you find most effective for the struggling students? What impact did they have on the students writing?
4. What challenges, if any, did you encounter during the writing component? Describe any modifications or accommodations you made to the writing component of lesson.
5. What part of the writing component would you change? How would you teach it differently?
6. What changes did you observe in the struggling student's critical thinking skills when they were required to justify their reasoning in writing? What were the common errors students made in their reasoning in writing? What were the strengths students demonstrated in their reasoning in writing?
7. What benefits do you think these students gained when sharing their writing with each other? Describe any changes in any struggling student's attitude when required to share his/her writing in class?

8. What trends in the writing component for GoMath do you notice are evident in your school? How do you think other special education teachers are implementing the writing component of the lesson?
9. What trends do you think are not evident? What do you think are some possible reasons?
10. What support would you welcome to enhance critical thinking in the writing instruction for struggling students? How often would you like the support?
11. What else would you like to add?

Appendix D

Mathematics Teacher Classroom Observation Protocol

Date: ______________________________ Teacher __________________
Grade: ______________________________ Time __________________
Type of Class ________________________

Descriptive Notes (Observation)	Reflective Notes (Researcher's Thoughts)
1. Teacher explains, reteaches, or implements modifications when necessary. ❑ Not observed ❑ Sometimes ❑ Most of the time ❑ Always	
2. Teacher questions engage students in exploring the mathematics content. ❑ Not observed ❑ Sometimes ❑ Most of the time ❑ Always	
3. Think time is allowed by the teacher before a student's response is given. ❑ Not observed ❑ Sometimes ❑ Most of the time ❑ Always	
4. Teacher probes for clarification that requires thought, such as an explanation or providing an example to support an answer. ❑ Not observed ❑ Sometimes ❑ Most of the time ❑ Always	
5. Teacher provides opportunity for all students to engage in discussion where students take the initiative. ❑ Not observed ❑ Sometimes ❑ Most of the time ❑ Always	
6. Effective teacher feedback is specific and descriptive to help students adjust what they are doing and help them become better problem solvers. ❑ Not observed ❑ Sometimes ❑ Most of the time ❑ Always	

Adapted from the Danielson Framework (2011)