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Writing to Learn Mathematics: A Mixed Method Study

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WRITING TO LEARN MATHEMATICS: A MIXED METHOD STUDY

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This study sought to address a research gap by studying students who had been taught mathematics using writing. The purpose of this study was to provide an analysis of students' perceptions of the benefits and drawbacks of this pedagogical approach. The types of writing students performed in mathematics classes were described, and students' preferences regarding these tasks were analyzed. Finally, a comparison was made between female and male students' responses in order to see whether gender played a significant role in shaping students' perceptions of writing as a tool for learning mathematics.

Using a mixed method design, data were collected from 293 middle school students in Western Pennsylvania. A survey was used to collect quantitative data. Qualitative data were collected from the student participants in the form of five open-ended questions. Students also submitted samples of writing from their mathematics classes.

Based on the results of the data analysis, it can be concluded that students had a positive attitude towards writing in mathematics classes. This was particularly evident among students who were struggling with mathematics. Students with lower letter grades (C, D, and F) indicated that they were much more in favor of mathematics classes that use writing.

The results also indicate that there is evidence of students' mathematical knowledge growth in the students' writings. In their responses to the open-ended survey questions, the students gave detailed explanations of how their approach to mathematics learning and their understanding of mathematical concepts had changed. Students' writing samples showed how the students were learning to use writing to explore alternative solutions to problems and also to check and reflect on their understanding of new mathematical concepts.

Finally, the findings of the study also suggest a clear benefit to female mathematics students from the use of writing as a tool for learning mathematics. When it comes to the problem of helping female students succeed in mathematics classes, this study shows that writing is the solution for which mathematics teachers have been searching.

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CHAPTER 1

INTRODUCTION

In 1983 the National Commission on Excellence in Education declared that the United States was "A Nation at Risk" based on U.S. students' poor performance in mathematics and science when compared with other countries. This historic alarm illuminates a widespread belief in the importance of mathematics. Mathematics holds a preeminent place among disciplines work in technology and hard sciences depend heavily on mathematical computations. Mathematics is also heavily tied to economics, business modeling and commerce, and even military weapons systems. Given the widespread uses of mathematics, it was easy to see alarm bells were sounded when U.S. students' mathematics scores began to lag behind the scores of children from around the world. For the U.S. to remain a dominant world power, many felt it needed to maintain a citizenry with a strong knowledge of mathematics. One great benefit of this outcry was that it spurred the National Council of Teachers of Mathematics (NCTM) to begin working on the *Curriculum and Evaluation Standards for School Mathematics.* These standards were in place by 1989 and quickly moved into widespread use, especially as they were integrated into textbooks and standardized tests.

Unfortunately, releasing a set of standards does not magically teach students how to learn mathematics. Though the NCTM standards are quite useful, mathematics remains one of the most difficult subjects to teach and to learn. Furthermore, Steen (2003) points out that despite the effort that has gone into mathematics education over the past twenty five years, not a lot has changed in terms of the poor mathematics performance of

American students. Mathematically the nation remains at risk. This study arises from this on-going and historic problem of poor student performance in mathematics. How can teachers help students improve their learning of mathematics?

In traditional mathematics courses, most instructional time focuses on teaching students how to solve problems that are going to be asked on a test or quiz (Morgan, Tsatsaroni, & 2002; Romberg, 1995). Students are taught problem solving methods and then they practice these techniques. This approach has been exacerbated by the emphasis No Child Left Behind Act (2001) has placed on student test performance. In this high stakes-testing era, mathematics students are often assessed only on their ability to solve problems and generate correct answers, regardless of their understanding of the mathematical concepts underlying those problems.

Study Background

Throughout the history of mathematics education, assessment has always been a prominent issue. Since the first half of the twentieth century, standardized testing has been used to assess students' performance. According to Earl (2003), large-scale assessment has become the vehicle of choice for holding schools accountable. Earl points out, however, that there is very little evidence showing how these large-scale assessments improve student learning. Nevertheless, the educational importance of standardized testing continues to grow with schools focusing more and more of their time, money, and effort on increasing the scores of their students.

Effects of Assessment Climate

For the past nine years, this researcher has taught seventh and eighth grade mathematics at a middle school in Western Pennsylvania. During that time there have

been several changes in the approaches to assessing students. At the end of the nineties, performance-based assessment, which had been given a lot of backing earlier in the decade, was losing its momentum. At the same time, there was a growing push for higher standards, especially with the passage of the Improving America's Schools Act (1994). This push to improve student achievement was also part of President Clinton's Goals 2000 which recommended that states all set up standards in core discipline areas.

In 2001, No Child Left Behind was signed into law as the latest reauthorization of the Elementary and Secondary Education Act of 1965. According to Yell and Dragrow (2005), the purpose of No Child Left Behind is to make sure all students achieve important learning goals. States are required to set standards and to demonstrate that all students are achieving these standards. Standardized tests are usually viewed as the simplest ways to measure this achievement. High stakes testing has thus become the primary method by which states attempt to demonstrate that their students are reaching federal requirements.

The No Child Left Behind Act reflects the political belief that if you increase the number of tests and the difficulty of those tests, students will learn more. But this belief is far from accurate. Throughout the literature (Heubert & Hauser, 1999; Neill, 2003), there is a persistent caution that the scores of standardized tests alone should not be used to make decisions about student ability. Neill (2003) points out that these scores are only estimates of students' knowledge and that they deal only with multiple choice and short answer type questions. What is needed, according to Neill, is a type of assessment or method of assessment that can demonstrate students' understanding of a high quality curriculum. Heubert and Hauser (1999) agree with this argument, stating that the scores

from high-stakes testing need to be combined with other sources of information about students.

Unfortunately, the heavy emphasis schools now place on standardized test scores provides an incomplete picture of students' mathematical learning. In a study examining the current state of assessment in public schools, Stiggins (2003) notes that the high-stakes tests currently in place "almost completely ignore the other 99% of assessments that happen in a student's life" (p. 199). Stiggins argues that all teachers should strive to gather dependable information about students' day-to-day learning.

While the time for performance-based assessment seems to have passed, we can still make use of a few key elements from this approach as we move to a new focus on problem-based learning. According to Khattri, Reeve, and Kane (1998), "performance assessments must require students to *structure* the assessment task, *apply* information, *construct* responses, and be able to *explain* [emphasis in original] the processes by which they arrived at the answers" (p. 2). This structuring, applying, constructing, and explaining can be seen throughout problem-based learning. "The emphasis of problem-based learning is on conceptual based learning rather than on the memorization of facts" (Lambros, p. 4).

Similarly, Wiggins and McTighe (2005) note the importance of keeping the form and purpose of assessment in mind when designing curriculum. They say effective assessment needs to provide a diverse picture of student abilities, making it "more like a scrapbook of mementos and pictures than a single snapshot" (p. 152).

I believe it is important that teachers examine students' individual work, progress, and self-reflection in addition to their standardized test scores so a more well rounded

assessment of each students' developing skills can be made. One potentially useful way of moving mathematics instruction beyond the limits of standardized testing is to incorporate writing activities into the mathematics curriculum. This study was designed to explore the benefits of using writing to teach mathematics.

Mathematics and Writing

A small group of studies supports the basic benefits of using writing activities in the mathematics curriculum (Baxter, Woodward, & Olson 2005; Gibson & Thomas, 2005; Miller, 1992, Ntenza, 2006; O'Connell Beamon, Beyea, Denvir, Dowdall, Friedland, & Ward, 2005; Shield & Galbraith, 1998). The main focus of these studies has been on describing the types of writing activities done in mathematics classrooms. Brandenburg (2002) discusses the importance of writing as an instructional tool for advanced mathematics students. Baxter, Woodward, and Olson (2005) point out the benefits of writing as a form of communication for low-achieving students. The present study will add to this general body of research on mathematics and writing by collecting and analyzing student perceptions of writing as a tool for learning mathematics.

Statement of the Problem

Though the majority of the studies listed above argue that writing activities enhance mathematics instruction, the studies also note that writing is rarely used as an instructional technique in the vast majority of mathematics classes. Many of these studies thus call for more research in this area. Additionally, none of these studies offers direct insight into students' views of writing as a mathematics learning tool.

My study sought to fill this gap. It adds to the limited research available on writing as a tool for learning mathematics. My study examined student perceptions of

how the use of writing in mathematics classrooms impacted student learning in a high-stakes testing environment.

To gain a clearer understanding of what students actually understand about the mathematics they are studying, one needs to assess students' thinking within the mathematics classroom. Writing is a tool through which teachers can examine what students comprehend of the mathematical concepts they are taught (Kennedy, 1999; Robinson 1998). Berryman and Russell (2001) argue that reflective writing provides the clearest picture of how well students have learned a particular mathematical concept.

Despite these claimed advantages to the use of writing for teaching mathematics, this pedagogical technique is not very widespread among mathematics teachers and research on this approach has been minimal. Shield and Galbraith (1998) note that while writing for mathematical learning has received some attention in the research literature, not much is known about the benefits of this approach and no descriptive studies have been made of the actual types of writing that are done in mathematics classrooms.

My study looked at how the use of writing in mathematics classes impacted female students. Traditionally, female students have performed less well than male students in mathematics classes (Fennema & Carpenter, 1998), so my study explored potential benefits which this pedagogical approach might hold for females. Klienfeld (1998) points out that there is a detailed body of literature on gender issues in schools from elementary grades through college. Some of this literature shows that female students generally receive higher grades, hold higher class rank, and receive more scholarships and awards than male students. However, Klienfield notes that awards for female students tend to be for writing while their male counterparts generally receive

greater recognition at science and mathematics fairs. If more writing was incorporated into mathematics classrooms, would this allow females to become more confident in their mathematical abilities and to strive toward more advanced mathematics classes? Campbell and Evans (1997) likewise consider some of the issues that prohibit females from taking more advanced mathematics classes. They observe that females tend to have stronger verbal skills whereas males tend to be better spatial thinkers; they argue that most mathematics courses deemphasize verbal skills.

The challenge of high stakes testing is compounded in mathematics when the issue of gender is also considered. Historically, females have performed poorly in comparison to males in mathematics study (Bilken & Pollard, 2001; Boaler & Greeno, 2000). Female mathematics students often perform poorly in situations which can be described as right answer only, such as standardized testing (Paechter, 2001).

The literature on writing in mathematics, discussed in greater detail in Chapter 2, seems to argue that this pedagogical tool holds promise for improving mathematics instruction for two main reasons: Writing gives mathematics teachers a way to see what their students think and understand about concepts and writing also seems to suit the verbal learning styles of female mathematics students. In light of those potentials, then, this study aimed to explore the promise of writing as a tool for learning mathematics from the perspective of mathematics students. If the study could show that students supported this technique, then more mathematics teachers might become willing to try using writing in their classes.

Purpose of the Study

This study sought to address a research gap by studying students who had been taught mathematics using writing activities. The purpose of this study was to provide a statistical analysis of students' perceptions of the benefits and drawbacks of this pedagogical approach. The types of writing students performed in mathematics classes were described, and students' preferences regarding these tasks were analyzed. Finally, a comparison was made between female and male students responses in order to see whether gender played a significant role in shaping students' perceptions of writing as a tool for learning mathematics.

Research Questions

This study focused on three main research questions. Each question was further detailed using two sub-questions:

Question One:

How do writing activities affect students' attitudes toward learning mathematics?

Sub-questions:

A. How do students in different levels of mathematics (e.g. Math 7, Pre-Algebra, Algebra, and Geometry) view writing in mathematics classes?
B. How do students who have earned different letter grades view writing in mathematics class?

Question Two:

What indications of mathematical knowledge growth and learner development can be found in student writing for mathematics classes?

Sub-questions:

A. How does the activity of writing change students' approach to preparing for tests and quizzes?
B. What evidence of mathematics knowledge growth can be found in samples of students' writing for mathematics classes?

Question Three:

How do writing tasks affect female students' learning of mathematics?

Sub-questions:

A. How does writing in a mathematics class affect female students' attitudes toward mathematics?
B. How does writing in a mathematics class affect the future career goals of female students?

The Research Project

To answer these research questions, this study focused on the following research project. First, an examination of the current scholarship was done to see how writing has been used in mathematics classrooms. Then a survey was administered to multiple mathematics classrooms in which students use writing as part of their study of mathematics. The survey was distributed to three teachers for a total 386 students. In addition to Likert scale type questions on students attitudes towards writing and mathematics study in general, there were several open-ended questions. In these questions, students were asked to discuss their thoughts and attitudes about using writing to study mathematics. Finally, samples of students' written work from their mathematics classes were collected and examined for evidence of types of learning taking place.

Definitions

1. Writing in mathematics class: The writing tasks used are categorized as reflective writing (expressing feelings and thoughts about what the mathematics students are learning) and expository writing (describing and explaining what the students are learning). This is the form of writing currently required in the open-ended writing tasks on many states' standardized tests (Pennsylvania School System Assessment).
2. Student attitudes: Students' feeling about mathematics classes in general, the amount of time they spend on homework, the writing assignments that are required in their mathematics classes, and the role mathematics will play in their future careers.
3. Mathematical knowledge growth: Evidence of clear student understanding of the mathematical concepts being studied. This evidence will be drawn from various writing samples that will be submitted by students.

Significance of the Study

The changing literacy needs of society put various demands on the role of writing in education. Teaching our students to write effectively should be the responsibility of all educators (Nagin 2006). According to Brahier (2001), many of the standardized tests now being used to evaluate students in mathematics have begun to include more open-ended response items: "These items provide evidence of conceptual understanding rather than the students' ability to answer direct, simplistic questions" (p. 7). Brahier goes on to point out that one of the main advantages of this type of testing (open-ended written responses) is to allow teachers to develop strong instructional strategies. This supports Lambros'

(2002) argument that students need to learn to demonstrate conceptual understanding rather than memorization of facts. Thus, the findings of their research project should assist mathematics educators in learning about a tool for helping students to strengthen their mathematical ability. This study aims to eliminate some mathematical difficulties students face by examining the benefits of using writing as a tool for teaching mathematics. Elbow (2004) states that "it is possible for anyone to figure out what he or she really means and finally get it clear on paper" (p. 9). Therefore, while many students may struggle with mathematical concepts, if the students are given an opportunity to write about the mathematics or the difficulties they are having, this act of writing may lead to better understanding.

Significance for the Researcher

This study is important for many reasons. One of the main significances for the researcher was an opportunity to study how to improve mathematics teaching. The study hopefully demonstrated ways in which writing on a day-to-day basis can be successful in a mathematics classroom. A second significance for the researcher is the study provided an opportunity to learn more about students' ways of thinking. The findings of this study should also help improve instruction.

Significance for the Participants

The study provided the participants an opportunity to reflect on their learning in the mathematics classroom. The participants were able to think about what they were learning and be able to put that learning into the context of their daily lives. The participants also hopefully found significance in the study because they were being given

a chance to voice their own thoughts about what are effective ways for them to learn mathematics. This study offered students a chance to speak.

Significance for Mathematics Educators

The significances for the individual researcher were also hopefully applicable for other mathematics educators. This study demonstrated ways in which writing can be a successful mathematics-teaching tool. While writing has been addressed in mathematics education research, Shield and Galbraith (1998) point out that the type of writing used has not been studied in detail. This study provided mathematics educators with new ideas on how to use writing as a teaching tool. Additionally, students' perceptions on writing in mathematics classes has not been examined to any great extent. In addition, the use of writing to close the achievement gap between male and female students has not been examined. Overall then this study hopefully provided support for other mathematics educators who are trying to improve teaching and learning in this era of high-stakes testing.

Limitations of the Study

Every researcher needs to be cautious as they approach a study. One can never be totally objective as there is always some level of subjectivity that will appear.

Researcher Bias

One limitation of this study is researcher bias. This researcher believes in the use of writing to teach mathematics and has used it extensively in her own mathematics classes in the past. This strong belief in the value of writing may have had an impact on

the success of the study. To guard against this bias in favor of writing, data were gathered directly from students in other teachers classes.

Effectiveness of Writing in Mathematics

A second potential limitation to this study may be whether it is possible to use writing successfully as a teaching tool in all mathematics classrooms. The success of writing in a mathematics class may be dependent on having an educator who believes in the power of writing as a teaching tool. Being able to use writing as a teaching tool may not be a strength for many mathematics teachers. Thus while this study may lead to recommendations to use writing in mathematics classes, those recommendations may need to be tempered based on individual teacher skills.

Conclusion

Overall, this study has the potential to revamp individual classroom assessment and point mathematics teachers in a new direction. At the very least, the study will give students a chance to speak directly about their mathematics learning styles. Finally, this study should provide mathematics educators a method of instruction that is meaningful for the students.

Chapter Overviews

In order to help readers through this study, the following is an outline of the remaining chapters.

Chapter Two provides a review of relevant literature in the areas of writing in the mathematics classroom, student perceptions of mathematics understanding, and gender issues in mathematics.

Chapter Three examines the methodology used to collect the data. This is a mixed methods study where 293 students were surveyed using a Likert Scale researcher-designed instrument. Several open-ended questions were included in the survey. Students were also asked to submit writings from their mathematics classes.

Chapter Four reports on the description and analysis of the data. A one-way ANOVA was run on the data. The open-ended questions were analyzed using a qualitative method of Inductive Analysis where students' attitudes were categorized based on emergent themes. Students' written work was scrutinized for statements demonstrating mathematical understanding, application of knowledge, and self-reflective learning. Statements were compared by gender.

Chapter Five contains a discussion of research findings for the three primary research questions. The chapter also offers a discussion of the implications of this research for teaching and research in the areas of mathematics, education, and writing studies. The chapter then covers limitations to the overall study and discusses future research projects which might grow from the present study. The chapter finishes with some closing thoughts about the overall value of the study.

CHAPTER 2

REVIEW OF LITERATURE

At its most basic level, this is a study of how to improve mathematics instruction. Any review of the research literature will show there are many ways one might improve the teaching of mathematics today (Burris, Huerbert, & Levin, 2006; Hook, Bishop, & Hook, 2007; Kilpatrick, 2006). Though there are many diverse ways to improve pedagogy, the No Child Left Behind Act 2001 primarily focuses on one mechanism for change: increasing assessment. One of the central premises of NCLB is that the only way to judge what students have learned is to test them frequently. For this reason, NCLB places heavy emphasis on having students take standardized assessments at regular intervals.

Unfortunately, the politicians who designed NCLB seem to have forgotten that taking a test is not the same as actually learning something. Tests often measure test-taking skills better than they measure conceptual knowledge. Chipman (2005) states that many standardized tests are "timed multiple-choice tests that reward test taking strategies such as guessing based on partial information" (p. 16). Standardized tests, of necessity, generally place major emphasis on correct answers. Scores from standardized tests thus often fail to tell teachers how much a given student really understands the mathematical concepts being studied (Chipman, 2005; Wainer & Steinberg, 1992)

Jerome Bruner's seminal work *The Process of Education* (1960) is useful for reflecting on some of the limitations of using high test scores as the only measure of educational success. In today's curriculum there is heavy emphasis on achieving high test

scores and earning good grades, but little time or emphasis placed on what Bruner called the "lure of curiosity and interest" (p. 50). The problem in many classrooms is that students focus only on the test that will be given at the end of a unit. For the average student, studying is done only to get a good grade. Students are not heavily encouraged to look beyond their texts and tests to see how mathematics works in real life situations. Students' intellectual curiosity, about mathematics and all subjects, needs to be aroused.

Bruner argued that students' curiosity could be developed by challenging students to perform rigorous tasks. For example, Bruner argued,

> The point has been made repeatedly that in the high school plane geometry is typically taught with excessive emphasis upon techniques, formal proofs, and the like, that much more attention needs to be given to the development of students who have a good intuitive feel for geometry, students who are skillful in discovering proofs, not just in checking the validity of or remembering proofs with which they have been presented. (p. 56)

Students need to be allowed to guess at an answer, and then provide a proof or explanation in their own terms for their answer rather than being punished for guessing wrong. Bruner calls this "intuitive thinking." He says "intuitive thinking is fostered by the development of self-confidence" (p. 66). This intuitive thinking is inhibited by the idea of a right or a wrong answer:

> We need to give our students practice in not only making educated guesses but also in recognizing the characteristics of plausible guesses provided by others--knowing that an answer at least is of the right order of magnitude, or that it is possible rather than impossible (p. 65).

Bruner's work pushes for a complex vision of teaching and learning, one not likely to be achieved just by making students take more standardized tests.

It is this gap between testing and knowledge growth that this study wishes to address. Building off of Bruner's still timely challenge, this study believes the goal of mathematics teaching must be much more than helping students to find the right answer to a given problem. Effective mathematics teaching means helping students learn how to think intuitively about mathematics and how to verbalize that thinking. This study takes as a central premise that the best way to see what students have learned about a mathematical concept is to ask the students to explain in writing what they understand. This makes writing a vital tool for assessing students' mathematical learning. Ntenza (2006), among others, supports this central belief of this dissertation that writing can be used effectively to teach mathematics.

This chapter will explore current research literature on the benefits of using writing to teach mathematics. The chapter begins by examining the basic question of whether writing has any place within the mathematics classroom. That question is addressed by providing a brief historical overview of the Writing Across the Curriculum (WAC) movement. Using WAC as a justification for linking writing to mathematics teaching, this literature review then turns to an examination of the types of writing activities reported in studies of mathematics classrooms. Next the pedagogical benefits of teaching mathematics using writing are explored, followed by a focused examination of how writing activities benefit female mathematics students, a group shown historically to face difficulties in learning mathematics.

Why Bring Writing into the Mathematics Classroom?

It might seem unusual, at the outset, to bring writing activities into the mathematics classroom. Most curricula in the United States keep disciplines isolated from each other, with mathematics and English perhaps being seen as the two disciplines which are the farthest apart. For most people mathematics is the realm of numbers, English the realm of words. Thus even though there are many ways to write about mathematics beyond simple story problems, when a mathematics teacher first asks students to engage in writing activities, the teacher's request is often met with bewilderment and even resistance.

Elbow (1994) attributes this difficulty to the problem of "binary thinking" (p. 179). According to Elbow, binary thinking is when things are looked at only in terms of opposites. People tend to think of mathematics and English as binary opposites even though numbers and words can both be used together to explain concepts. This binary view of mathematics and English persists, though, because people have been taught to think of the differences between academic disciplines as fixed. That is, almost all schools separate the study of mathematics and English. While this is not the only way to construct a curriculum, people tend to think of it as the only way because they haven't seen any other models. People come to believe in the binary separation even though that separation is, at least to an extent, created primarily for convenience.

Subject Isolation

Though the disciplines have never been totally isolated from each other, certainly on a practical level mathematics, English, science, and other disciplines are normally

taught individually. Standardized assessments of student knowledge in these areas are also primarily broken down into individual disciplines.

Of course on some level this separation of the disciplines really does make good sense. Much of the work in mathematics education focuses on helping students learn how to manipulate abstract concepts. Geometric planes and linear equations are much easier to explain through equations and graphs than verbally. Still, there are some very real problems which result from keeping academic subjects highly compartmentalized.

Mathematics, in particular, is a discipline which has come to be seen as especially cut off not only from the other academic disciplines, but from the rest of the world. Students regular challenge mathematics teachers with the question, "When will I ever use this?" This question arises partly because students view mathematics as a discipline disconnected from everything else. Romberg (1997) points out that in too many mathematics classrooms, students are taught only formal mathematical properties with little effort made to connect mathematical concepts to other disciplinary knowledge. Romberg observed that most mathematics classes fail to address the applications of mathematics beyond the classroom. According to Romberg, "all students must have numerous experiences in school mathematics . . . and only through such experiences will students come to mathematically understand the rapidly changing world around them" (p. 7).

Even though it can be problematic, a disciplinary-based structure and subject isolation remain a cornerstone of public education in the United States. While individual teachers might, occasionally, introduce material with some small consideration for what else is going on in the mathematics department, rarely do teachers consider their work in

light of other departments in the school (Reilly, 1997). Students are taught the material necessary to move on to the next concept in a disciplinary sequence, but they receive little instruction about how concepts in one discipline might be applied in another area. For example, geometry teachers may spend weeks and weeks teaching about proofs without ever mentioning the way proof is used in law.

Disciplinary isolation is an artifact of the history of curricular development in the U. S. In fact, the eminent philosopher John Dewey was concerned with the educational effects of disciplinary isolation problem as early as 1916: "In the traditional schemes of education, subject matter means so much material to be studied. Various branches of study represent so many independent branches, each having its principles of arrangement complete within itself" (p. 135). Dewey felt this rigidly isolated structure often made education seem too abstract and meaningless to students. A disciplinary curriculum structure can easily lead to a focus solely on content coverage at the expense of finding more complex ways to engage students' natural intellectual curiosity.

As Dewey feared, because mathematics, science, English, and other subjects are regularly taught in isolation from one another, students often fail to see how learning one subject applies to any other subject, let alone real life. FitzSimons (2005), for instance, discusses the difference between the numeracy actives required in the workplace and the mathematics that students learn in school. FitzSimons describes ten different career opportunities, from fundraising to chemical handling and spraying, which require forms of numeracy that students do not study in standard curricula. He claims that "teaching and doing mathematics in school do not reflect the activity of being a mathematician" (p. 39). Abt-Perkins and Pagnucci (1993) take the argument even further, advocating

teaching methods which connect disciplines and allow students to lay their own claims to knowledge. Reilly and Pagnucci (2007) also argue for the need to develop more integrated curricula, noting their fear that "when students leave our classrooms, they see no connections between the subjects and anything else in their other classes or their daily lives" (p. 497). These teacher researchers report on an interdisciplinary project that asked mathematics students to make use of art and storytelling as the students collaboratively researched mathematics concepts.

Writing Across the Curriculum

For most of its history, the academic disciplines have remained largely isolated from each other in United States education. However, during the 1970s and 1980s, some progress was made toward breaking through these disciplinary boundaries when a movement called Writing Across the Curriculum (WAC) began to gain momentum at many United States universities. WAC, or WID (Writing in the Disciplines) as it is sometimes referred to, was built on the central beliefs that writing is a powerful pedagogical tool for developing student thinking and that this tool can be an effective teaching tool in any discipline.

Bringing writing more firmly into the mathematics classroom is the focus of this study, and the basis for this idea is grounded in the WAC movement's views about writing as thinking tool. Langer and Applebee's *How Writing Shapes Thinking* (1987) is a seminal study on the pedagogical practice of using writing as a teaching tool. According to Langer and Applebee, writing allows students to think and reflect in a focused way on the content about which they are writing. In fact, Langer and Applebee argue, when whenever students are asked to write about a particular concept, they gain a

greater understanding of that concept because writing requires active thinking: "Thinking skills are taught best when related to some content, the argument goes, and writing provides a particularly welcome context for thinking deeply about such content" (Langer and Applebee, p. 1). Langer and Applebee also argue that writing can be an invaluable means for evaluating student understanding: Writing "can be used to diagnose students' needs and it can reflect students' ability to apply what they know" (p. 57).

Along the same lines, Tchudi (1986) also discusses the perceived importance of writing as a teaching tool. "The claim in the 1980s is not simply that content teachers ought to include writing in their disciplines in order to teach writing, but that they should use it as a means to improve education" (p. 16). Tchudi argues that to build a strong curriculum every content teacher should make use of writing. To some extent these recommendations have found a place in many of today's content classes: in mathematics and science, for example, students are often now asked to answer open-ended questions that involve detailed written explanations of the thought process involved in reaching a problem's solution.

In the early stages of the WAC movement, WAC proponents argued that teachers in all disciplines should make writing a central part of their pedagogical practices. WAC usually gained ground on campuses through a series of professional development workshops in which faculty members from across the disciplines were taught basic principles for using writing in their courses. One lasting element of the WAC movement was the development of writing centers at universities in the United States. In *Writing Centers and Writing Across the Curriculum: Building Interdisciplinary Partnerships* Barnett and Blummer (1999) have put together a collection that describes the

collaboration that has taken place and continues to take place between writing centers and WAC programs in colleges and high schools across the country.

According to Stock (2001), WAC was built around the principle of language and learning. “It was meant to remind all teachers at all levels of instruction that language—written and spoken—is the most readily accessible and powerful means of learning” (p. 97). In other words, allowing students to write their own thoughts and feelings about material they are studying in any classroom can lead to students achieving a better understanding of that material. Britton, Burgess, Martin, McLoed, and Rosen (1975) describe this use of writing for learning as exploratory writing where students are asked to compose thoughts and ideas about new subjects. Knoblauch and Brannon (as cited in Stock, 2001) also discuss this idea, stating that this exploratory writing allows teachers to engage students in learning through their own language. Herrington (1981) also emphasizes that “the ‘writing-to-learn’ approach implies that students do have something to say and that the process of writing provides at once the way for them to discover and communicate it” (p. 379). Overall, WAC argued that using writing would help students become more effective learners of all subjects.

Today, the basic principle of WAC—using writing as a learning tool, has taken hold in many disciplines. According to Friedman (2000), teachers of content areas such as science and mathematics acknowledge the need for writing in order for students to demonstrate their understanding of the material being studied. Friedman also notes that many science and math teachers prepare students to write responses to open-ended questions that are asked on state standardized tests. Many major universities have programs to help faculty with writing across the curriculum. There is also currently a

biannual international conference on Writing Across The Curriculum that has drawn participants from as many as 16 countries and has been in place for sixteen years. Finally, *The WAC Journal* is published annually as a collection of articles by educators on their WAC ideas and experiences. "It is a journal of practical ideas and pertinent theory" (retrieved from http://wac.colostate.edu/journal/ May 28, 2007).

What Are the Benefits of Writing for Learning Mathematics?

In the National Council of Teachers of Mathematics (NCTM) *Curriculum and Evaluation Standards for School Mathematics* (1989) and *Principles and Standards for School Mathematics* (2000) communication is addressed as a standard for each of the four benchmark years (Grades Pre-K-2; Grades 3-5; Grades 6-8; and Grades 9-12):

> Communication is an essential part of mathematics and mathematics education. It is a way of sharing ideas and clarifying understanding. Through communication, ideas become objects of reflection, refinement, discussion, and amendment. The communication process also helps build meaning and permanence for ideas and makes them public. (NCTM, 2000, p. 60)

Writing is a primary tool for communication, so one way to achieve NCTM's goal of teaching students effective communication skills is to bring writing into the mathematics classroom.

Development of Communication Skills

Baxter, Woodward, and Olson (2005) discuss one approach for teaching students mathematical communication skills through writing. They argue that in order to develop mathematical proficiency, students need to learn to communicate their mathematical thinking: "Students develop a more coherent and robust understanding of mathematical

ideas by expressing their thinking in writing, even if that writing is less precise than formal mathematical expressions" (p. 132). In other words, as long as students are given the opportunity to write in mathematics classes, even informally, this writing allows for student reflection and clarification of concepts. This in turn should lead to students developing a better overall understanding of mathematics.

Communication, according to Clarke, Waywood, and Stephens (1993), is the core of all classroom experiences that stimulate learning: "Mathematical meaning requires a language for its internalization within the learner's cognitive framework and for its articulation in the learner's interactions with others" (p. 235). In order to truly understand mathematics, students need not only the ability to internalize mathematical concepts but also an ability to share that understanding with others. Clarke, Waywood, and Stephens go on to say that when students write about their thinking, this activity can be both challenging and empowering.

Improved Learning and Understanding

In order to really see if a student understands a concept in mathematics, the teacher needs to look beyond the right or wrong answer. In a numeric solution to a problem, a teacher can see whether or not a student solved a problem correctly, but not whether the student understands why a problem is to be solved that way or how the formula relates to an actual real-world relationship. Thus writing can offer a tool for unpacking students' thinking about and understanding of the mathematics concepts they are being taught.

According to Shield and Galbraith (1998), writing can indeed improve students' learning and understanding of mathematics: "Writing is thought to promote a

personalized and constructive approach to learning" (p. 30). Shield and Galbraith reported on a study they conducted that investigates mathematical understanding of the students as reflected in their writing. Shield and Galbraith found that an analysis of the writing provided "indications of the ways students' writing may be developed in order to stimulate a deeper understanding" (p. 44). The writing tasks used in their study were categorized as journal writing (expressing feelings and thoughts about the mathematics students are learning) and expository writing (describing and explaining what the students are learning). Expository writing is the form of writing that is currently required in the open-ended writing tasks of many states' standardized tests (Pennsylvania School System Assessment, 2007). However, it should be noted that the writing that occurs in a mathematics classroom is often constrained by the style of writing that is presented to the students in their textbooks. Therefore, students often tend to give the same style of expository writing they see presented to them.

Kenyon (1989) also discusses the benefits of writing as a way to improve learning and understanding. Kenyon's work connects writing to problem solving in mathematics: "Problem solving involves application of learned knowledge and skills in order to move through a process of resolving a situation" (p. 76). When students are asked to write thoughts and procedures, Kenyon notes, this adds another dimension to the learning process, that of being able to see a possible solution for a problem.

Noted composition scholar Peter Elbow also lends support to the idea that writing can improve students' understanding of new ideas. He claims that writing can be used "to help students comprehend and clarify concepts" (p. 13).

Active Learning and Critical Reflection

In addition to the other benefits noted above from having students write in mathematics classes, it is also worth briefly addressing a few other key ways composition scholars have argued that writing benefits students: this in the areas of active learning and critical reflection.

Pioneering composition scholar Janet Emig (1977) studied the composing processes of twelfth graders. She observed that writing engaged students in active learning because the act of writing involves the hand, eye, and brain simulataneously. This makes writing a uniquely powerful multi-representational mode for learning. Emig claimed, "Writing involves the fullest possible functioning of the brain, which entails active participation in the process of both the left and the right hemispheres" (p. 125). In addition to learning re-enforcement, Emig noted that writing makes information visible and immediately available for reflection and feedback.

Elbow (2004) also notes that writing involves active participation on the part of the student: "Writing puts words and thoughts into students' heads" (p. 10). Elbow claims writing makes students answer the question "What do you have to say?" (p. 13), a question which forces students to actively engage with the ideas about which they are writing.

Looking more interdisciplinarily, the National Writing Project and Nagin (2006) also support the claims that writing fosters active learning and critical reflection. They argue that "writing is a complex activity; more than just a skill or talent, it is a means of inquiry and expression for learning in all grades and disciplines" (p. 3).

The work of Nagin and the National Writing Project follows the idea put forward by Langer and Applebee that writing shapes thinking and learning. As the National Writing Project and Nagin point out, not only does an effective writing assignment ask students to write about what they have read or experienced, it also engages them in a series of cognitive processes such as reflection, analysis, and synthesis. They also claim that "writing tasks can improve learning retention" (p. 54) and "help students reflect and think critically about content" (p. 54).

Overall, then, it seems clear that writing in mathematics classes can provide students with a powerful thinking tool not available to students who are only asked to work with numbers and formulas.

Drawbacks to Using Writing to Learn Mathematics

Fulwiler (1984) notes that while WAC has been generally quite successful, there have been some unexpected problems in its deployment. Mathematics has been a discipline where writing has found less of a foothold. There are two reasons for this difficulty according to Fulwiler. The first reason has been the *terminology* used to describe the different functions of writing that can be used in any classroom. Fulwiler reports on three function of writing he used in workshops on WAC. These included "expressive (personal informal writing to yourself to find out what is on your mind); transactional (writing to inform, instruct, or persuade someone about something); and poetic (writing used as art, where form, structure, and style may be more important than content)" (pp. 114-115). While many participants of the WAC workshops came to understand the difference between the different functions of writing, problems arose when these participants had to return to their own departments and explain the functions

to colleagues who had not attended the workshops. Disciplines like mathematics and business have trouble accepting the idea that informal writing can be used to as a method of formal communication especially if there is poor sentence structure and incorrect spelling.

The second is *translation* Fulwiler says. Teachers who use writing need to be able to adapt different strategies, practices, and techniques of good writing to their particular discipline. He notes that mathematics teachers seem to struggle with this as they may fail to see how it is possible to bring writing into the math class. Since some mathematics material is not very conducive to writing, many mathematics teachers believe story problems are the only way of using writing in a mathematics class.

One more reason WAC may not have been adopted heavily by mathematics teachers is the basic difficulty people have in formulating mathematical concepts using words. Yet while students may find it difficult, at least initially, to verbalize their mathematical thinking, it also is quite difficult for teachers to understand the type of mathematical thinking students are doing without having students verbalize their problem solving processes. This argument thus favors the use of writing in mathematics classes, even if this pedagogical approach provides some challenges to students. A persistent belief in the value of writing for teaching mathematics has fueled a dedicated group of teachers and researchers to explore this topic. An overview of this research on writing and mathematics is the focus of the next section of this literature review.

What Types of Studies Have Been Done on Writing and Mathematics?

A variety of research supports the basic benefits of using writing activities in the mathematics curriculum (Birken, 1989; Davison & Pearce, 1988; Ediger, 2006; Gibson & Thomas, 2005; Glynn & Muth, 1994; Gopen & Smith, 1990; Meier & Rishel, 1998; Ntenza, 2006; O'Connell Beamon, Beyea, Denvir, Dowdall, Friedland, & Ward, 2005; Pearce & Davison, 1988; Pugalee, 2004). Though the research on writing and mathematics is diverse, it can, for a convenient means of comparison, be divided into three major categories which are discussed in this section. These include types of writing activities, impact on mathematics teachers, and writing as a voice for students.

Types of Writing Activities

The majority of the studies on writing and mathematics focus on describing the various writing activities that teachers ask their students to perform in their classrooms. The following provides a brief description of some of the types of writing activities that were commonly used in the mathematics classes which have been studied.

Mett (1989) says one of the most common writing tasks used in mathematics classes is *journal writing*. Journal writing allows students to keep a record of their thoughts and feelings. This form of writing can be very personal in nature where the main audience will be the teacher only. A journal allows for feedback to be provided by the teacher on an individual basis. Journal entries usually are not graded or evaluated, but teachers do normally make follow-up responses to the students' journal entries. According to Pugalee (1997), the journal can be a place for students to think aloud. When students have trouble solving a problem, Pugalee suggests that students use their journal

to get their thought processes going. Journals can help students think through the problem-solving process (Borasi & Rose, 1989; Shield & Galbraith, 1998).

Composing *summaries, essays,* and *explanations* are other types of writing sometimes used in mathematics classrooms. According to King (1982), summaries and explanations can help students synthesize material. King argues that writing often can be more beneficial than class discussions because writing enables each student to provide an individual response to the current mathematics topic. Abel and Abel (1988) state that essays allow students to explain both the advantages and disadvantages of mathematical concepts.

Impact on Mathematics Teachers

Several writing and mathematics studies focus on how mathematics teachers are impacted by using writing as a teaching tool. Miller (1992) describes how students' writing can provide a rich resource for teachers. "By reading students' writings, teachers access a source of information usually unavailable to them, and by responding to what students wrote, teachers engage in a unique and continuous dialogue that contributes to the whole process of teaching and learning" (p. 338). In other words, from reading students' writings, teachers can gain information about a student's understanding of a particular mathematical concept that may otherwise not be evident from regular classroom participation or even perhaps formal classroom assessments.

Several studies emphasize the importance of educators regularly examining the writing techniques they use in their classrooms and making sure these meet the needs of the students currently enrolled in the class (Connolly & Vilardi, 1989; Holiday, Yore, & Alvermann, 1994). Stonewater (2002) stresses the importance of providing examples of

both acceptable and unacceptable writing assignments and of providing feedback when students are working on a particular writing assignment. As a way for mathematics teachers to monitor the effectiveness of their writing assignments, Stonewater provides a writing assignment checklist and suggests, "In the spirit of 'classroom- based research' add to or modify the checklist and adapt it to your own teaching situations" (p. 333).

Brandenburg (2002) and Burns (2004) both discuss how writing can be used by teachers as an assessment tool and by students as a way to self-monitor learning. Burns notes that writing provides a way for "students to reflect on their own learning and to explore, extend, and cement their ideas about the mathematics they study" (p. 30). These studies also suggests that teachers need to be prepared to change or adapt their lesson plans if they see in students' writings indications that things are not going well and students are not clearly understanding the mathematical concepts being introduced by the teacher.

Writing As a "Voice" for Otherwise Silent Students

A small number of writing and mathematics studies look at how writing provides a voice for students who for one reason or another are afraid to speak out in their mathematics classes. Baxter, Woodward, and Olson (2005) point out that one of the main challenges for all mathematics teachers is to find ways to include all students in meaningful communication. In their study of writing in a mathematics class for low-achieving students, the researchers noted that one benefit of the writing work was that these tasks gave students, who were normally quiet in class, a "voice" with which to demonstrate their knowledge. Baxter, Woodward, and Olson said that normally, if a student is not participating in whole class discussions, teachers assume this student does

not understand the concept or is not working hard. This may not be the case, however, and the researchers said that in the class they studied, students used the writing tasks to demonstrate their mathematical reasoning and conceptual understanding. Baxter, Woodward, and Olson remark, "Students who did not actively participate in mathematics discussion did respond when asked to write about mathematical ideas" (p. 130)

Interestingly, students in the study began to take a more active class role after being asked to write in their mathematics class. In addition, several students in Baxter, Woodward, and Olson's study wrote in their journals that they liked being able to express confusion and difficulties with mathematical concepts in privacy, rather than having to do so in a class discussion where they might be judged or ridiculed by their peers. In addition to being able to "voice" their difficulties in private through their writings, students also reported that the writing enabled them to have a one-on-one correspondence with their mathematics teacher and so the students were able to discuss other feelings about the class.

Audet, Hickman, and Dobrynina (1996) also point out that writing allows teacher and student communication to go beyond traditional classroom experiences. They state that this type of dialogue can include conversation that is "chatty, friendly, and often witty" (p. 219). This can sometimes break down the barriers that exist between students and teachers. Beins (1993) and Solomon and O'Neill (1998) report that when students are allowed to use their own words, students tended to focus more on the context and rationale of their mathematics class.

All of these studies are based on comments students made in their written texts produced for their mathematics classes. As such, the comments provide some incidental

glimpses into what students think about being asked to write as a way to learn mathematics. While in general the students appear to perceive writing as valuable for their work in mathematics, these studies were not focused directly on researching student perceptions of writing as a tool for learning in mathematics. This gap in the research is the focus of the next section.

How Do Students View Writing in Mathematics Classes?

While the preceding section shows there is a somewhat well developed body of research on mathematics and writing, one element missing from this research is a direct examination of students' perceptions of writing as a tool for learning mathematics. Though various studies argue, particularly from the instructor's view, that writing is an effective method for teaching mathematics, this argument has not yet been corroborated with data drawn from mathematics students themselves. This study aims to provide some of that missing data.

While research on mathematics students' views of writing is limited, there are some studies that discuss students' perceptions of being asked to write responses in mathematics classes (Clarke, 2001; Cooley, 2002; Barnes, 1999; Fellows, 1994; Keys, 1994; King, 1982; Nahrgang & Peterson, 1986; Powell & Ramnauth, 1992). Fried and Amit (2003) call their study of students' point of view a "Learners' Perspective Study (LPS)." In LPS the students' mathematics notebooks are examined for writings that show reflection on what is learned rather than looking at the students' work only for solutions to problems that are being taught. "LPS focuses on student actions within the context of whole-class mathematics practice whereby students' reconstructions and reflections are considered," explain Fried and Amit (p. 93). The main goal of such research, therefore, is

to use students' writings to see how they perceive mathematics learning. As with the "voice" research, students' texts are used as the source of data here rather than directly surveying students about their perceptions of writing as a mathematics learning tool.

Albert (2000) reports on a study where students were interviewed about the writings they submitted throughout the course of the study. While some of the students acknowledged the fact that some people can do the math in their heads, students in this study said they felt that being able to write allowed them to "get a better picture of what was going on" (p. 127). Students also stated that being allowed to write provided them the opportunity to go back and reread their notes to help them remember concepts better. As with Fried and Amit (2003), one of Albert's conclusions is that writing allows students to reconstruct knowledge in their own words, an integral part of the learning process.

Brandenburg (2002) discusses the importance of writing as an instructional tool for advanced mathematics students. Brandenburg reports that after discovering her pre-calculus and calculus students had trouble applying techniques to unfamiliar situations, she decided to investigate the use of writing as a teaching aid. Brandenburg found writing provided "a tremendous increase in students' comprehension and their ability to explain what they already knew" (p. 67). By being asked to write in their mathematics classes, Brandenburg said "students learned to formulate and express their mathematical thinking" (p. 68).

Overall, it seems clear from the reported studies that students do perceive some basic benefits to writing in mathematics classes. However, much of this data is limited and indirect. Given the changing nature of the mathematics education climate, there

appears to be a need to obtain further and more direct data on students' perceptions of writing to learn mathematics.

How Do Female Students Benefit from Writing Activities?

Certainly the general lack of data on students' perceptions of writing in mathematics classes is one compelling reason to pursue this line of research. But there is another important reason as well. Several studies have argued that writing is an especially valuable way to develop success for female science and mathematics students (Connolly & Vilardi, 1989; Harding, 1979; Rivard, 1994; Smail 1987).

Female Versus Male Learning Styles

Mathematics and science have always been considered male dominated fields where white men of European decent have had the most success. Paechter (2001) points out that men "are likely to be relatively comfortable with mathematics because it resembles other ways in which they approach important questions in their lives" (p. 53-54). This can be linked to Gilligan's theory (1993) on moral decision-making and the different approaches men and women take. While Gilligan does not mention mathematics per se, her discussion of the way boys and girls approach games can be applied to the mathematical field. According to Gilligan boys approach games in an independent and organized manner and can follow an elaborate set of rules. Girls, on the other hand, tend to prefer to interact more with small groups and deal more with relationships. This can certainly be applied to the way mathematics is organized. The independent, isolated units of mathematical concepts in most cases can stand alone and are usually taught following a very individualistic approach.

Paechter agrees with Gilligan in that one of the reasons women often have trouble with mathematics is because the subject requires women to "change their dominant mode of thinking" (p. 54). Mathematics and science tend to require more rational thought than is required in other disciplines. Rational thinking is more typical of the way men think than women says Paechter.

Tannen (1990) points out that male dominance is not the only issue, that "the effect of dominance is not always the result of the intention to dominate" (p.18). Tannen discusses gender differences when it comes to ways of speaking: "Many frictions arise because boys and girls grow up in what are essentially different cultures" (p. 18). To apply what Tannen, Gilligan, and Paechter are saying to mathematics, both genders have different strengths, so varying instructional methods may be the best pedagogical approach.

While Tannen argues that women and men think in quite different ways, Vygotsky's (1978) research shows that people learn through exposure to the ideas of others, even when those ideas are different. Vygotsky points out that learning has begun long before a child has ever reached school. This learning takes place in the environment around the child and includes questions asked of and answers given to the child by the adults in the child's world. Vygotsky builds on the stages theory of child development put forth by Piaget (1960, 1970). Vygotsky does this by stating that learning should be in some way matched with the developmental stage of the child. The zone of proximal development, as defined by Vygotsky, is the distance between the actual development of the child and the potential development of the child. In other words, with a little guidance from a more capable peer, the child can become an independent learner for the concept

been considered. Vygotsky claimed that the zone of proximal development demonstrated that development lags behind learning, that mastery of a concept is the beginning of a stage of development. In mathematics, one can apply Vygotsky's ideas by having students of various abilities help each other with different types of mathematical concepts.

Saxe (1990) discusses how Vygotsky showed that "social interactions were a critical vehicle whereby natural processes in cognitive development were redirected by social and historical influences" (p. 10). Pedagogically, having students work with other students who have similar backgrounds and yet can provide a challenge for their classmates should lead to intellectual development for all. Saxe reports the findings of a study he conducted on the important learning that can occur when students of a variety of backgrounds are allowed to work together. One of the findings he notes is the ability of children to apply their "out of school knowledge to make sense of classroom mathematics" (p. 138).

While Vygotsky's work argues that students learn better when they are placed with other students who have different thoughts, ideas and abilities, Tannen and Gilligan's work has shown that boys and girls approach learning and life differently. This difference between boys' and girls' learning styles also needs to be taking into account in mathematics classroom in order to improve educational opportunities for all students.

Female Students' Difficulties with Mathematics

According to Plucker (1996), when it comes to math and science, females are underrepresented. In addition to not taking higher level math and science classes, females

are also not achieving as high as their male counterparts on standardized tests (Reis, 1991).

Biklen and Pollard (2001) summarize the results from a number of studies that looked at differences in mathematics performance based on gender. They note the "long-standing outperformance of boys as compared to girls on standardized tests" (p. 738), though they also mention that this gap has closed a bit in recent years. Biklen and Pollard conclude their overview of gender and mathematics research by noting that poor female performance in mathematics classes "is an issue of gender relations . . . not a question of math genes" (p. 739).

The influence of parents plays an important role when it comes to students' attitudes towards math and science (Leedy, LaLonde, & Runk, 2003). Leedy, LaLonde, and Runk found that girls had less confidence when it comes to the study of math and that their mothers had lower expectations for their daughters' success in mathematics. Leedy, LaLonde, and Runk support Pluker (1996) by stating that teachers behaved differently towards girls than boys when it came to mathematics instruction. The authors stress the need for developing classrooms that "are geared towards conceptual and discovery learning" (p. 290) to offset potential gender biases. Also, students need to be taught to ask the question "why?' while learning basic skills and when trying to understand concepts. Britton et al. (1975) argue that having students do reflective or expressive writing in mathematics and science was a key way teachers could help students address "why?" questions.

Several factors also influence a student's decision to continue studying mathematics. Boaler and Greeno (2000) discuss the important role teachers plays in

students' interest in mathematics classes. In Boaler and Greeno's study, all students appreciated an opportunity to discuss and question mathematics material. "Students regarded their role to be learning and understanding mathematical relationships; they did not perceive mathematics classes to be a ritual of procedural reproduction" (p. 182). Throughout Boaler and Greeno's study, students were asked to contribute more of themselves to the learning that was taking place. In contrast, when knowledge is presented in rote form, girls and minorities tend to be more alienated as these groups may have a difficult time expressing themselves. In fact, Meece and Jones (1996) found one of the reasons that girls were not well represented in mathematics and science is due to innate gender differences in visual-spatial abilities. As Boaler and Greeno point out "traditional pedagogical practices will maintain inequality in the attainment and representation of mathematics students at the highest levels even when stereotypical societal expectations diminish" (p. 197). When mathematics class is viewed more in context as a series of relationships, girls and students of minorities can gain more ownership. If students are given a chance to conceptualize how mathematical relationships are formed, they can build more on prior knowledge and have more success, argue Boaler and Greeno.

Improving Female Performance in Mathematics

Females outperform males in reading and writing at all grade levels on the National Assessment of Education Programs (NAEP), but white males scored higher than all other groups in mathematics and science according to Coley (2001). In light of this disparity, several studies report on ways to support activities that allow female students to make use of their verbal skills to clarify ideas which can lead to more self-confidence

when working in mathematics and science (Barnes & Coupland, 1990; Marr & Helme, 1990).

Isaacson (1990) reports on a math class that had 24 women in a Hitecc (Higher Introductory Technology and Engineering Conversion Courses) course in London that recruited only women. From an informal discussion with the students before the class began Isaacson, the instructor, realized the fears these women had about having to take a mathematics class. So she decided to begin the class by having the students write a mathematical biography, a paper in which students wrote on memories that were important to them about learning math. Many of the students discussed being the only girl in a class and being afraid to ask for clarification or help. Others discussed the competitive nature of other math students, in particular boys, and the often militaristic style of male teachers. Still others discussed not wanting to pursue math because "they were better at English." By allowing these students to write about their previous experiences in mathematics classes, Isaacson said she gave the students a voice and allowed the students to give their perspective on the subject of math.

In 1997 Boaler conducted a study which found that female students in a traditional textbook-orientated mathematics class did not perform as well in understanding mathematics as females who were in a project-orientated mathematics class that emphasized writing and student initiated learning. Boaler argued that traditional problem-solving based approaches to teaching mathematics sometimes alienate female students. Changing teaching methods, such as allowing students to have more input by using writing, may thus be a way to improve girls' learning of mathematics.

This chapter provides a general overview of the research on writing and mathematics. It starts from the traditional position which views mathematics and writing as polar opposites. This belief is traced to disciplinary isolationism. The review then shows how the WAC and WID movements helped make room for writing within non-English disciplines, thereby breaking down at least some of the problems of discipline-limited thinking.

Though efforts to promote WAC across the U.S. met with a certain degree of success, mathematics tended to be less receptive of the move to incorporate writing into its pedagogy. However, a body of research on writing and mathematics has been developed and it is discussed here. One gap in this research is a lack of focus on student perceptions of writing pedagogy in mathematics classes. This gap creates a need for the present study. Finally, this literature review concludes by noting the potential benefits writing pedagogy has for addressing the historic gender inequity problems which have plagued the discipline of mathematics. The potential value of writing for helping female students to learn mathematics provides one further important argument for the value of the present study.

CHAPTER 3

METHODOLOGY

In this chapter I will describe the research design I have chosen for conducting this study. The purpose of this study was to provide a statistical analysis of students' perceptions of the benefits and drawbacks of using writing to teach mathematics. The study described and analyzed the types of writing students do in mathematics classrooms and explored which types of writing activities preferred by students. Finally, this study examined how learning mathematics through writing varies by student gender.

This study focused on three main research questions. Each question is furthered detailed using two sub-questions:

Question One:

How do writing activities affect students' attitudes toward learning mathematics?

Sub-questions:

C. How do students in different levels of mathematics (e.g. algebra, geometry, trigonometry, calculus, etc.,) view writing in mathematics classes?

D. How do students who have earned different letter grades view writing in mathematics class?

Question Two:

What indications of mathematical knowledge growth and learner development can be found in student writing for mathematics classes?

Sub-questions:

A. How does the activity of writing change students' approach to preparing for tests and quizzes?
B. What evidence of mathematics knowledge growth can be found in samples of students' writing for mathematics classes?

Question Three:

How do writing tasks affect female students' learning of mathematics?

Sub-questions:

A. How does writing in a mathematics class affect female students' attitudes toward mathematics?
B. How does writing in a mathematics class affect the future career goals of female students?

The remaining sections of this chapter outline the exploring of these questions and sub-questions.

Research Design

A mixed-method approach was used for this study. A mixed-method study integrates both quantitative and qualitative research methods (Gay & Airasian, 2003). Much debate has occurred since the 1960s on the usefulness of combining qualitative and quantitative research methodologies in the same study (Creswell, 2003; Curlette, 2006; Taskakkori & Teddlie, 1998; Thomas, 2003). As Stewart and Shields (cited in Thomas) state, "the debate was often viewed as a contest between innovative, socially responsible methods versus obstinately conservative and narrow-minded methods [others viewed the debate as between] precise, sophisticated techniques versus mere 'common sense'" (p. 6).

While a number of scholars remain entrenched in binary views of quantitative and qualitative research methods, other scholars advocate views of these methods which are complementary. Curlette (2006) for instance, argues that "beliefs from the qualitative aspect of a mixed methods research design can be combined with data from the quantitative side of the research to reach a belief statement about the existence of a finding from the qualitative study" (p. 345). In other words, Curlette believes data collected using qualitative techniques can be used to support conclusions reached by performing tests on quantitative data and vice versa.

One benefit of using a mixed-method study according to Frechtling, Sharp, and Westat (1997) is that combining the two approaches sharpens our understanding of the research findings. For example, rejecting a quantitative null hypothesis can be clarified by using some of the comments made by students in open-ended qualitative responses. According to Hanson, Creswell, Plano-Clark, Petska, and Creswell (2005), "using both forms of data allows researchers to simultaneously generalize results from a sample to a population and to gain a deeper understanding of the phenomena of interest" (p. 224). In other words, a researcher can make generalizations from the sample to a population which is normally something done by a quantitative researcher. These generalizations can be further supported and enhanced through thick descriptions of some aspects of the data, an approach normally taken by qualitative researchers.

Of course, mixed-method research designs are not without their disadvantages. According to Creswell (2003), the mixed-method researcher has to be knowledgeable in both qualitative and quantitative designs. This generally requires more time and effort on the part of the researcher. Leahey (2007) states another concern with mixed-method

research, the confidentiality of human research subjects. Leahey points out the difficulties that arise for researchers who use qualitative data to support quantitative findings and the importance of protecting the identities of the human subjects. According to Collins, Onwuegbuzie, and Jiao (2006), a third concern to mixed-method research is sampling size. In quantitative research the larger the number of subjects the more reliable the findings will be. With qualitative data, it is not always possible to work with a large number of subjects as the researcher needs to be able to analyze that data in more depth. Additionally, certain research questions may not lend themselves well to both approaches. The two approaches can also be at odds philosophically; for instance, while a quantitative researcher aims to generalize, a qualitative researcher working from a narrative inquiry approach usually refuses to generalize (Pagnucci, 2004). However, these disadvantages are not enough to deter this researcher in this project.

Types of Mixed Designs

This study employed a mixed-method approach using inferential statistics supported by qualitative surveying. Gay and Airasian (2003) refer to this type of research as QUAN-QUAL "which integrates simultaneous qualitative and quantitative methods with equal weight" (p. 185). For this study, qualitative and quantitative data will be collected at the same time and emphasized as evenly as possible in the analysis of the data.

Instrument Description

The main instrument of data collection in this study is a researcher developed survey(Appendix A). According to Sapsford (2006) one the main benefits to a survey is it is flexible and can deal with different types of data. Thomas (2003) states that "surveys

are useful in revealing the current status of a target variable within a particular entity" (p. 44). A survey was chosen as the primary instrument for this study to facilitate testing hypotheses about the attitudes of students towards writing in mathematics classes. The survey used a Likert Scale model. A Likert Scale asks participants to respond to a series of statements based on a limited range of possible answers. Students were asked to respond to a series of items by indicating whether they Strongly Agree (SA), Agree (A), Disagree (D), or Strongly Disagree (SD). The items were divided into five main categories:

- mathematics in general
- writing in math class
- mathematics teacher
- open-ended responses
- demographic information.

Each category of survey topic is linked to a specific research question. After doing some research on survey design (Alreck, 2004; Fowler, 2002; Punch, 2003), the researcher developed a survey on students attitudes towards writing in mathematics. The survey contained five sections. The first section had eight items that deal with mathematics in general—students' attitude regarding math class, homework, group work, and current math grade. The second section had six items that deal with writing in mathematics class. These items address students' attitudes towards writing in math class and writing in other classes. The third section contained eight items that dealt with the students' mathematics teacher. The fourth section contained five open-ended items asking students to describe types of writing activities in their mathematics class. The final section focused on demographic information. Each response was assigned a point value and the students'

survey score was determined by summing the point values. A high point value will be used to indicated that the item statement is favorably rated by the student.

Pilot Testing

A draft version of the survey was pilot tested in an eighth grade class in the spring of 2006. These students shared similar backgrounds with the target participants for this study. The pilot study participants were all in mathematics classes that regularly had writing as part of the mathematics curriculum. After completing the survey, twelve students were asked to comment on the survey questions. The pilot survey was also distributed to several mathematics teachers along with initial versions of the research questions and these teachers provided commentary on the structure of the survey. The teachers also discussed how they felt each of the survey items could be used to address the research questions. Using the feedback from the students and teachers, several survey items were revised to clarify the wording. Several items were also removed which did not directly provide data that pertained to the research questions. In addition, this pilot research work was used to revise all the research questions and to clarify and refine the sub-questions.

Open-ended Questions

The research instrument also included five open-ended survey questions where students were able to add to the data their own narrative views about writing in mathematics class. Students were asked to submit a sample of their classroom writing to be analyzed by the researcher. A qualitative approach was used for analyzing both the open-ended questions and the writing samples.

This qualitative research provided deeper insight into students' feelings about writing in mathematics class and how writing activities contribute to the students' learning. Findings from the open-ended questions and the document analysis were used to enhance the findings of the inferential statistical tests performed on the quantitative data.

Research Site

This study was conducted in middle and junior/senior high schools in Western Pennsylvania. Three teachers will responded to the researcher request to study their mathematics classes. This allowed the researcher access to 15 classes with surveys distributed to between 300 and 400 students.

Teacher/Researcher Involved in the Study

Potential teacher participants were drawn from a pool of people who attended a conference presentation on writing in mathematics classes. The researcher, as part of a Pennsylvania Council of Teachers of Mathematics (PCTM) annual conference, conducted this presentation. The researcher used participants of this PCTM session as a pool of potential study teacher participants. The researcher contacted by email teachers who attended this session, asking if the teachers would be interested in participating in this study. The teachers who participated in the conference do not teach in the district where the researcher teaches.

Once teachers indicated an interest in participating in this study, their superintendents were contacted to gain permission to conduct the study at the teachers' schools. Following this, students and their parents were contacted about the study and invited to participate. Those students willing to participate in the study were surveyed.

Students Involved in the Project

The students surveyed for this project were all students enrolled in mathematics classes that frequently use writing as part of their mathematics curriculum. Students were between twelve and fourteen years of age. This age range was chosen since it is the typical age of students in middle school and junior high school mathematics classes. Both males and females were included in this study. Because the subjects are under age eighteen, parental permission was obtained in order to survey the students.

Data Collection

Research data for this study was collected in the natural classroom environment. The primary source of data for the study was the students' surveys. This study was designed to make students active participants in the research process. A cover letter describing the purpose of the survey was distributed to the students in their mathematics classes by their math teacher (Appendix B). Attached to this cover letter was an informed consent form (Appendix C). This consent form was signed by students and their parents in order for students to participate in the study. The students who decided to participate returned this letter with both a parent/guardian signature and a student signature to the regular mathematics teacher. A survey instrument was administered to students who agreed to participate (Appendix A). Using a Likert Scale format, the students responded to 28 items focusing on their study of mathematics and their use of writing in mathematics classes. The quantitative data were obtained from these items. The next five questions on the survey were open-ended questions. Through their responses to these open-ended items, students had an opportunity to describe what is working and what is not working when they use writing in their mathematics classrooms. More importantly,

students were given an opportunity to state why they thought a particular writing activity was useful. The researcher responded to these student comments in the qualitative analysis of the data. There were seven demographic questions at the end of the survey. Finally, student writing samples were collected from study participants to gauge the range of writing being done in these mathematics classes. These samples were read, described, and analyzed.

Data Analysis

Data analysis consisted of examining survey answers, student responses to the open-ended questions, and students' mathematics writing samples. Data were analyzed using three categories: survey analysis; questionnaire analysis; and document analysis. Tables 1, 2, and 3 summarize the three research questions, the survey items that provided the data on those questions, and the data analysis done to answer those research questions.

Table 1

Research Question 1

Research Question 1	Survey Items	Data Analysis
How do writing activities affect students' attitudes toward learning mathematics? <u>Sub questions:</u> 1.A. How do students in different levels of mathematics (e.g. algebra, geometry, general math, etc) view writing in mathematics classes? 2. B. How do students who have earned different letter grades view writing in mathematics class?	9. I often have to write in mathematics classes 10. I enjoy writing in mathematics class 11. 1 enjoy writing in other classes 12. I understand the math concepts better if I have to write about them at the end of a unit 13. A math class that uses writing activities helps you learn better than a math class that does not use writing activities. 14. Doing even more writing activities in math classes would improve my learning/understanding.	• Descriptive Statistics • Inferential Statistics: One-way ANOVA

Table 2

Research Question 2

Research Question 2	Survey Items	Data Analysis
What indications of mathematical knowledge growth and learner development can be found in student writing for mathematics classes? Sub questions: 2. A. How does the activity of writing change students' approach to preparing for tests and quizzes? 2. B. What evidence of mathematics knowledge growth can be found in samples of students' writing for mathematics classes?	29. Describe how some writing activity chan the work you did for a math quiz or test. 30. Describe in detail one writing activity you have done for math class. 31. List some of the other types of writing activities you have done for math class. 32. How has writing changed the way you learn math? 33. What do you think is important about using writing to learn math?	• Inductive Analysis • Document Analysis

Table 3

Research Question 3

Research Question 3	Survey Items	Data Analysis
How do writing tasks affect female students' learning of mathematics? <u>Sub questions:</u> 3.A. How does writing in a mathematics class affect female students' goals for post secondary education? 3.B. How does writing in a mathematics class affect the future career goals of female students?	1. Math is a challenging subject 2. I work to the best of my ability in math class 3. Math homework helps me better understand the math concepts 4. I find the material in my math class difficult 10. I enjoy writing in mathematics class 11. 1 enjoy writing in other classes 25. What role do you believe math will play in your future? 34. Gender 36. What career would like to have? 37. Current math class	• Descriptive Statistics • Inferential Statistics: T-Test

Descriptive Statistics

Frequencies and percentages for respondents' answers were calculated. In addition to a frequency table for gender-related responses, other variables were analyzed using descriptive statistics.

Inferential Statistics

A one-way ANOVA and an independent sample t-test were used to examine students' attitude and gender toward writing in a mathematics class. Several hypothesis tests were carried out to answer research questions 1 and 3. These tests examined the difference between different variables and male and female math performance.

Inductive Analysis

Research question 2 was answered using inductive analysis. Students' attitudes towards writing in mathematics class was categorized based on emergent themes. The data for this analysis was taken from the responses the students give to the five open-ended questions at the end of the survey. Both inductive and interpretive analysis was performed on the open-ended responses and the written pieces: Hatch (2002) defines inductive data analysis as "a search for patterns of meaning in data so that general statements about phenomena under investigation can be made" (p. 161). For this study, students' writing samples were analyzed for common beliefs and concerns students raise related to their use of writing as a tool for learning mathematics. Additional emergent themes were sought in these writing samples. Descriptions of the types of writing students do in mathematics classes and how these writing activities have helped to

prepare students for tests and quizzes were used to support and elaborate on the findings from the quantitative data analysis.

Document/Interpretive Analysis

According to Thomas (2003) interpretive analysis provides meaning that goes beyond the mere description of the data. Interpretive analysis will be used in this study to give meaning to the quantitative statistics. According to Hatch (2003), "the logic of the interpretive model parallels that of the inductive model in that pieces are put together in meaningful relation in order to construct explanations that help readers make sense of what is being examined" (p. 181). In other words, examining students' writing in mathematics will allow me to expand on my findings from the inferential statistical analysis and enable a better interpretation of that data.

Students' written work was examined for statements demonstrating mathematical understanding, application of knowledge, and self-reflective learning. Statements were also be compared by gender. This data were analyzed to confirm themes derived from the qualitative analysis of the open-ended questions.

Reliability and Validity

"Reliability is the degree to which a test consistently measures whatever it is measuring" (Gay & Airasian, 2003, p. 141). In other words, reliability is used to gauge whether the same results be obtained if this study was to be replicated. Because the pilot test for this study was only administered once, internal reliability was assessed using split-half reliability. According to Bryman and Cramer (2005), "with split-half reliability the items in a scale are divided into two groups and the relationship between the respondents' scores for the two halves is computed" (p. 77). A correlation coefficient

closer to 1 indicates that a scale is more internally reliable. In addition, *Cronbach's alpha* was also calculated. *Cronbach's alpha* calculates the average of all possible split-half reliability coefficients. With both the split-half reliability coefficient and *Cronbach's alpha* a score of .8 is preferable. The *Cronbach's alpha* was .64 on the pilot test and the split-half reliability coefficient was .62. To raise these scores for the current study, weak items were eliminated if they appeared to significantly reduced the reliability coefficient. While neither of these scores are equal to or greater than .8 the pilot score were close and the changes made to the survey after the pilot testing should improve reliability.

According to Gay and Airasian (2003), validity is the most important characteristic a measuring instrument can possess: "Validity is concerned with the appropriateness of the interpretations made from the test scores" (p. 133). To be effective a study must look at both internal and external validity.

Internal validity is checked using face validity. "Face validity is the extent to which the measure is subjectively viewed by knowledgeable individuals as covering the concept" (Sirkin, 1999, p. 73). After the pilot test was administered, several students were given the opportunity to discuss the survey items. Based on this student feedback, wording of many of the items was changed for clarification. Several mathematics teachers also read the survey with a copy of the research questions and were asked to provide feedback on the appropriateness of the survey items. Again this lead to changes in the survey question wording which helped improve internal validity.

In order to check for external validity, construct validity was examined. "Construct validity has to do with the ability of the scale to measure variables that are theoretically related to the variable that the scale purports to measure" (Sirkin, 1999, p.

74). For example, students who do not like to write in mathematics class may not like writing in other classes and may fail to see how writing can help them do better in any subject. Also students who do not have a positive attitude toward writing in mathematics class may not have a positive attitude toward mathematics class in general. The most common measure of correlation is Pearson's Product Moment Correlation Coefficient, or Pearson's r. With the pilot study data, the Pearson's r was calculated using the following variables: enjoy writing in math class, enjoy writing in other classes, and enjoy math classes. The following table represents the findings:

Table 4

Correlations

		I enjoy writing in math	I enjoy writing in other classes	I enjoy math class
I enjoy writing in math	Pearson Correlation	1	.606(**)	.193(*)
	Sig. (2-tailed)	.	.000	.030
I enjoy writing in other classes	Pearson Correlation		1	.132
	Sig. (2-tailed)		.	.140
	N	126	126	126

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The table shows that there is a strong correlation (.61) between students who like writing in other subjects and those who like writing in math. However there is not a strong correlation (.19) between those who like writing and those who enjoy math. Therefore, it is hoped that students who are allowed to write in math class can use their preference for writing to gain more enjoyment of mathematics. Analysis of the current survey data will follow a similar approach to the above analysis done for the pilot study.

Chapter Summary

In this chapter, I have focused on three main sections. The first section dealt with the mixed-method approach used for this research design. The second section dealt with data collection. I have discussed the schools in which the research will take place and the students participating in the study. In the last section, I outlined the various stages of the data collection process and described my data analysis procedures. In the next chapter I will describe the results of the study.

CHAPTER 4

DATA ANAYLSIS

The purpose of this study was to examine students' perceptions of the benefits and drawbacks of using writing to teach mathematics. This study sought to address a research gap by studying students who have been exposed to writing activities in mathematics classes. Consideration was given to the types of writing students do in mathematics classrooms and which types are preferred by students. Finally, this study examined how writing in mathematics classes impacts gender.

Chapter 4 presents the results of an analysis of the quantitative and qualitative data collected from students through survey instruments designed by the researcher. The survey was administered in three middle schools in Western Pennsylvania in spring 2007. A total of 293 students were surveyed.

Instrument

A survey was chosen as the primary research instrument for this study to facilitate testing hypotheses about the attitudes of students towards writing in mathematics classes. The survey used a Likert Scale. Participants responded to a series of items by indicating whether they Strongly Agree (SA), Agree (A), Disagree (D), or Strongly Disagree (SD).

The survey contained five sections. The first section had eight items that dealt with mathematics in general: students' attitude regarding math class, homework, and group work, as well as their current math letter grade. The second section had six items that dealt with writing in mathematics class. These items addressed students' attitudes towards writing in math class and writing in other classes. The third section contained eight items that dealt with the students' mathematics teacher. The fourth section

contained five open-ended items asking students to describe types of writing activities in their mathematics classes. The final section focused on demographic information.

Participants

Selection Method

Participants in the study were students of teachers who use writing as part of their mathematics curriculum. Eight teachers who attended a conference presentation on writing in mathematics classes were contacted and asked to participate in the study. Participation in the study was voluntary.

Response Rate

Out of the eight teachers originally contacted, three teachers agreed to allow their classes to be surveyed. The surveys were mailed to the three schools where these teachers taught. Two hundred and ninety three students out of a total of 386 students (76% return rate) completed the survey. According to Gay and Airasian (2003), a response rate of 60% or lower may lead to some questions about the generalizability of a study's results. The response rate for the present study was much higher than Gay and Airasian's threshold.

In addition to filling out a survey, students also sent samples of writing activities they had done for mathematics classes. The following is a breakdown of the writing samples collected from each of the three teachers:

Teacher 1	75 samples
Teacher 2	46 samples
Teacher 3	58 samples

To protect the students' identity, students were asked to remove their names from the writing samples before submitting them. This procedure was followed based on a recommendation by IUP's Internal Review Board. Preserving anonymity, while useful, did prevent the possibility of sorting the samples based on any demographic information. Instead, all writing samples were analyzed collectively and categorized based on the nature of each samples written content.

Non-participants

At least brief consideration should be given to the students who chose not to participate in the study since non-participants, even a small number as in this study do shape results to a degree. There are some likely reasons why students may have chosen not to participate in the present study. Since the students needed to have obtained parent/guardian signatures before they completed the survey, some students may simply not have gotten the consent form signed in time. The target age for this study was 12 to 15 years. At this young age not all students are able to effectively handle the responsibility of getting a parent/guardian signature. So some non-participants could easily be due to youthful forgetfulness.

Another reason students may have declined to participate in the survey was because they were asked to submit samples of writing with their surveys. While students were not required to submit samples in order to fill out a survey, some students may have felt they could not effectively participate if they had no writing sample to share. Of course some students or their parents/guardians may simply have been uninterested in the study. Others may have been intimidated by the consent form which can sometimes be confusing to people. Finally, it is possible that a few students who dislike writing in

mathematics chose not to participate because the research study focused on something they disliked. Still non-participants could just as easily have been pro-writing as anti-writing. With the non-participant rate being only 24%, the overall results of the study seem sound based on Gay and Airasian's work.

Participants

The following two tables provide an overview of the participants in the study. Looking at the first table one can see that while the responses were not equally distributed by gender, there is a good representation of both female (44%) and male (56%) students. Given that 66% of the participants were in eighth grade, this also leads to the highest percentage of students being in algebra (54%). In all of the schools, surveyed algebra was considered primarily an eighth grade class. Table 1 illustrates the frequency data for the demographic variables related to the sample participants.

Table 5

Frequency Table for Grade Level, Math Class, and Gender

Variable	Categories Response Number (Valid Percentages)			
n = 293				
Math Class	Math 7	Pre-Algebra	Algebra	Geometry
	20 (6.8%)	103 (35.2%)	158 (53.9%)	12 (4.1%)
Grade Level	Seventh Grade	Eighth Grade		
	100 (34.1%)	193 (65.9%)		
Gender	Male	Female		
	163 (55.6%)	130 (44.4%)		

Table 6

Descriptive Statistics and Frequency Table for Dependent Variables

N = 293

Variable	M	SD	Strongly Agree	Agree	Disagree	Strongly Disagree
Math is challenging	2.59	.79	35(11.9%)	125(42.7%)	112(38.2%)	21(7.2%)
Like group work*	3.17	.87	123(42%)	113(38.6%)	42(14.3%)	14(4.8%)
Enjoy math class*	3.00	.86	86(29.4%)	142(48.5%)	41(14.0%)	23(7.8%)
Prefer a class with writing	2.40	.75	15(5.1%)	119(40.9%)	126(43.0%)	33(11.3%)
Understand more when writing	2.14	.86	17(5.8%)	81(27.6%)	123(42.0%)	72(24.6%)

* missing one response

Table 5 illustrates the descriptive statistics for the dependent variables. The dependent variables represented survey items that utilized a four-point Likert scale that included "Strongly Agree" (4), "Agree" (3), "Disagree" (2), and "Strongly Disagree" (1). Since 4 was the most supportive or favorable result and 1 was the least supportive or least favorable response, 2.5 was considered to be the midpoint. Therefore, participant responses on survey items with a mean of 2.5 or greater are referred to as supportive, and responses with means less than 2.5 are referred to as less supportive or unfavorable responses. Two of the variables had means below 2.5; "Prefer a class with writing" and "Understand more when writing." However, the mean for the first variable (Prefer a class with writing) is 2.4, which is quite close to the favorable responses. It should be noted that even if students say they do not like writing in math class, it may still help them learn.

When the data for the five listed variables were analyzed, the sample group of two hundred and ninety-three indicated that they had negative feelings towards writing in a mathematics class. However, when one examines the variables in relation to each other, one can see that the sample group are closely divided when it came to looking at "prefer a math class with writing" with 54.3% choosing strongly disagree or disagree with this statement and 45.7% choosing agree or strongly agree with this statement. Yet almost 80% (77.9%) either agree or strongly agree that they "enjoy math class." All participants were from classes where writing was used extensively in their mathematics class and according to the teachers some students had been writing in math class for several years. While 66.6% "disagree" or "strongly disagree" with the statement that writing helps them understand mathematics, some of this lack of understanding can be attributed to the fact that almost 54.6% "agree" or "strongly agree" with the statement that math is challenging. In other words, because some many students find math challenging this may lead them to dislike math and as a result might not like writing about math. Nevertheless, this does not mean the activity is not useful. It does mean that mathematics teachers face challenges in getting students to like both writing and math.

A summary of these descriptive statistics could indicate that the sample group perceived writing in mathematics more negatively than positively. However, it can be seen in table 2 that while the students find their mathematics class challenging (55%) a large percentage enjoy mathematics overall (78%).

Results

The following two sections report the results for each of the three research questions. Inferential Statistics were used to answer research questions 1 and 3. These

tests examined the effects different variables had on students' attitudes towards writing in a mathematics class and also male and female math performance in mathematics classes that used writing. Research question 2 was answered using inductive analysis. The data for this analysis was taken from the responses the students gave to the five open-ended questions at the end of the survey.

Research Question One: Attitudes Towards Writing

Research Question 1 was: "How do writing activities affect students' attitudes toward learning mathematics?" To answer this question, responses from the survey were analyzed using a one-way ANOVA test. Items numbered 9 through 14 on the survey addressed question 1. The following dependent variables were examined:

Variables

- I often have to write in mathematics classes
- I enjoy writing in mathematics class
- 1 enjoy writing in other classes
- I understand the math concepts better if I have to write about them at the end of a unit
- A math class that uses writing activities helps you learn better than a math class that does not use writing activities.
- Doing even more writing activities in math classes would improve my learning/understanding.

Research Question 1 was divided into two sub-questions which are discussed in the following sections.

1. A. How do students in different levels of mathematics (e.g. Math 7, Pre-Algebra, Algebra, and Geometry) view writing in mathematics classes?

Null Hypothesis

There is no significant difference between the levels of mathematics students take and how often students have to write in math class.

There is no significant difference between the levels of mathematics students take and students enjoyment of writing in mathematics class.

There is no significant difference between the levels of mathematics students take students enjoyment of writing in other classes.

There is no significant difference between the levels of mathematics students take and students understanding of math concepts after writing about them.

There is no significant difference between the levels of mathematics students take and students view that writing activities help them learn better.

There is no significant difference between the levels of mathematics students take and students view that doing more writing activities would help them learn better.

Alternative Hypothesis

There is a significant difference between the levels of mathematics students take and how often students are required to write in math class.

There is a significant difference between the levels of mathematics students take and students enjoyment of writing in mathematics class.

There is a significant difference between the levels of mathematics students take students enjoyment of writing in other classes.

There is a significant difference between the levels of mathematics students take and students understanding of math concepts after writing about them.

There is a significant difference between the levels of mathematics students take and students views that writing activity helps them learn better.

There is a significant difference between the levels of mathematics students take and students views that doing more writing activities would help them learn better.

Table 7

Summary Table of Descriptive Statistics for the Variables of Students' Attitudes Towards Writing in Mathematics Class

Variable	Math Class	N	M	SD
Often have to write in math class	Math 7	20	2.85	.49
	Pre-Algebra	103	3.08	.72
	Algebra	158	2.98	.68
	Geometry	12	2.50	.67
Enjoy writing in math class	Math 7	20	1.90	.72
	Pre-Algebra	103	2.11	.80
	Algebra	158	2.03	.84
	Geometry	12	2.08	.51
Enjoy wring in other classes	Math 7	20	2.40	.78
	Pre-Algebra	103	2.23	.92
	Algebra	158	2.32	1.01
	Geometry	12	2.67	.98
Understand more when I write	Math 7	20	2.20	.62
	Pre-Algebra	103	2.21	.89
	Algebra	158	2.09	.86
	Geometry	12	2.17	.83
More writing would help	Math 7	20	1.90	.45
	Pre-Algebra	103	2.48	.74
	Algebra	158	2.31	.80
	Geometry	12	2.25	.87
Prefer a math class with writing	Math 7	20	2.20	.62
	Pre-Algebra	103	2.51	.74
	Algebra	158	2.36	.78
	Geometry	12	2.17	.72

Table 8

Summary of Univariate Analysis of Variance (ANOVA) for Variables of Students' Attitudes towards Writing in Mathematics Class

Variables	Source of Variation	*SS*	*df*	*MS*	*F*	*p*
Often have to write in math class	Between Groups	4.07	3	1.36	2.89	.04*
	Within Groups	135.87	289	.47		
	Total	139.95	292			
Enjoy writing in math class	Between Groups	.85	3	.28	.43	.73
	Within Groups	189.38	289	.66		
	Total	190.23	292			
Enjoy writing in other classes	Between Groups	2.30	3	.77	.83	.48
	Within Groups	268.05	289	.93		
	Total	270.36	292			
Understand more when I write	Between Groups	.95	3	.32	.43	.73
	Within Groups	213.74	289	.74		
	Total	214.69	292			
More writing would help	Between Groups	5.96	3	1.99	3.42	.02*
	Within Groups	167.92	289	.58		
	Total	173.87	292			
Prefer a math class with writing	Between Groups	3.04	3	1.015	1.80	.15
	Within Groups	163.03	289	.57		
	Total	166.08	292			

* $p < 0.05$

Summary of Findings for Research Sub-question 1A.

A one-way ANOVA was performed to examine six variables across the levels of mathematics students take. Each variable is discussed separately.

1. Often have to write in math class: The analysis of variance performed on writing in math class and the levels of mathematics students take yielded a p value of .04. Since $p < \alpha$, the null hypothesis was rejected. This result indicates that there is a significant difference among the levels of mathematics students take and how often students are required to write. A Post Hoc test was then run to investigate the difference between the different mathematics levels (see table 9). The asterisk indicates a marginally significant (at the $p < .05$ level) difference between two groups. These groups were pre-algebra and

geometry. It can be noted that when examining the descriptive statistics, the group of students in pre-algebra had a higher mean (M = 3.08) that all other mathematics levels of students. This indicates that this group of students said they do the most writing in mathematics class.

Table 9

Post Hoc Test for Often have to Write in Math Class Multiple Comparisons

(I) current math class	(J) current math class	Mean Difference (I – J)	Error	*p*
Math 7	Pre-algebra	-.23	.17	.61
	Algebra	-.13	.16	.89
	Geometry	.35	.25	.58
Pre-algebra	Algebra	.10	.09	.74
	Geometry	.56*	.21	.06
Algebra	Geometry	.48	.21	.14

2. Enjoy writing in math class: The analysis of variance performed on enjoy writing in math class and the levels of mathematics students take yielded a *p* value of .73. Since $p > \alpha$, the null hypothesis was not rejected. This result indicates that there is no significant difference among students in different levels of math classes and their enjoyment of writing in math class. Since there is no significant difference, there is no need for a post hoc test.

3. Enjoy writing in other classes: The analysis of variance performed on enjoy writing in other classes and the levels of mathematics students take yielded a *p* value of .48. Since $p > \alpha$, the null hypothesis was not rejected. This result indicates that there is no significant difference among students in different levels of math classes and their enjoyment of writing in other classes. Since there is no significant difference, there is no need for a post hoc test.

4. Understand more when I write: The analysis of variance performed on understanding when writing in math class and the levels of mathematics students take yielded a p value of .73. Since $p > \acute{\alpha}$, the null hypothesis was not rejected. This result indicates that there is no significant difference among students in different levels of math classes and their understanding when writing in math class. Since there is no significant difference, there is no need for a post hoc test.

5. More writing would help: The analysis of variance performed on more writing would help in math class and the levels of mathematics students take yielded a p value of .02. Since $p < \acute{\alpha}$, the null hypothesis was rejected. This result indicates that there is a significant difference among students in different levels of math classes and their view that more writing in math class would help. A Post Hoc test was then run to investigate the difference between the different mathematics levels (see table 10). The asterisk one table 6 is one pair whose mean differ significantly (at the $p < .05$ level) from each other. It can be noted that when examining the descriptive statistics, the group of students in pre-algebra had a higher mean (M = 3.08) than all other levels of mathematics. This means that this group of students said they more writing would help them in mathematics class.

Table 10

Post Hoc Test for More Writing Would Help Multiple Comparisons

(I) current math class	(J) current math class	Mean Difference (I – J)	Error	*p*
Math 7	Pre-algebra	-.58*	.19	.02
	Algebra	-.42	.18	.15
	Geometry	-.35	.28	.67
Pre-algebra	Algebra	.16	.10	.43
	Geometry	.23	.23	.82
Algebra	Geometry	.07	.23	.99

6. Prefer a math class with writing: The analysis of variance performed on prefer a math class with writing and the levels of mathematics students take yielded a p value of .12. Since $p > \acute{\alpha}$, the null hypothesis was not rejected. This result indicates that there is no significant difference among students in different levels of math classes and their enjoyment of writing in other classes. Since there is no significant difference, there is no need for a post hoc test.

Summary of Research Sub-question 1A: Six variables were analyzed to address Research Sub-question 1A, namely, students often have to write in math class, students enjoyment of writing in math class, students enjoyment of writing in other classes, students understanding more when they write, students feelings that more writing would help with math, and students preferring a class with writing. Students' level of mathematics was also reported using 4 categories, math 7, pre-algebra, algebra, and geometry.

Using SPSS, a one-way ANOVA of the responses was computed for each variable to determine the *p*-probability. For comparison an accepted alpha of 0.05 was used for each variable to decide to reject or maintain the null hypothesis. Based on this one-way ANOVA the following conclusions about levels of mathematics and attitudes

towards writing in mathematics class can be made. Four of the six null hypotheses made were not rejected based on the analyzed data. No statistically significant differences were found between the levels of mathematics and the variables students" enjoyment of writing in math class, students enjoyment of writing in other classes, students understanding when they write, and students preferring a class with writing. Two variables, however, did result in the null hypothesis being rejected. These were students writing in math class and students feeling that more writing would help. After a post hoc analysis was performed it was noted that when students in pre-algebra were compared to other groups, pre-algebra students continued to show a marginal significant difference. The positive response rate among this group of students was also higher than the other 3 groups which would indicate that the pre-algebra students had a more positive attitude toward writing in mathematics class and also would favor mathematics classes that use writing over mathematics classes that do not use writing as a teaching tool.

1. B. How do students who have earned different letter grades view writing in mathematics class?

Null Hypothesis

There is no significant difference between the grades students earned in mathematics class and how often the students have to write in mathematics class.

There is no significant difference between the grades the students earned in mathematics class and their enjoyment of writing in mathematics class.

There is no significant difference between the grades students earned in mathematics class take and their enjoyment of writing in other classes.

There is no significant difference between the grades students earned in mathematics class and their understanding of math concepts after writing about them.

There is no significant difference between the grades students earned in mathematics class and their view that writing activity helps them learn better.

There is no significant difference between the grades students earned in mathematics class and their view that doing more writing activities would help them learn better.

Alternative Hypothesis

There is a significant difference between the grades students earned in mathematics class and how often the students have to write in math class.

There is a significant difference between the grades students earned in mathematics class and the enjoyment of writing in mathematics class.

There is a significant difference between the grades students earned in mathematics class take and their enjoyment of writing in other classes.

There is a significant difference between the grades students earned in mathematics class and their understanding of math concepts after writing about them.

There is a significant difference between the grades students earned in mathematics class and their view that writing activities help them learn better.

There is a significant difference between the grades students earned in mathematics class and their view that doing more writing activities would help them learn better.

Table 11

Summary Table of Descriptive Statistics for the Variables of Students' Attitudes Towards Writing in Mathematics Class

Variable	Math Grade	N	M	SD
Often have to write in math class	A	123	2.95	.73
	B	136	3.00	.67
	C	29	3.00	.60
	D	4	3.25	.96
	F	1	3.00	--
Enjoy writing in math class	A	123	2.04	.85
	B	136	2.02	.77
	C	29	2.20	.77
	D	4	2.25	.96
	F	1	2.00	--
Enjoy writing in other classes	A	123	2.28	1.01
	B	136	2.30	.94
	C	29	2.34	.86
	D	4	2.75	.96
	F	1	3.00	--
Understand more when I write	A	123	2.13	.85
	B	136	2.13	.88
	C	29	2.20	.82
	D	4	2.50	1.00
	F	1	3.00	--
More writing would help	A	123	2.28	.75
	B	136	2.38	.79
	C	29	2.38	.78
	D	4	2.50	1.00
	F	1	3.00	--
Prefer a math class with writing	A	123	2.40	.74
	B	136	2.38	.76
	C	29	2.41	.78
	D	4	2.50	1.00
	F	1	3.00	

Table 12

Summary of Univariate Analysis of Variance (ANOVA) for Variables of Students' Attitudes towards Writing in Mathematics Class

Variables	Source of Variation	*SS*	*df*	*MS*	*F*	*p*
Write in math class	Between Groups	.50	4	.12	.26	.91
	Within Groups	139.45	288	.49		
	Total	139.95	292			
Enjoy writing in math	Between Groups	.99	4	.25	.38	.83
	Within Groups	189.24	288	.66		
	Total	190.23	292			
Enjoy wring in other classes	Between Groups	2.30	4	.36	.38	.82
	Within Groups	268.05	288	.93		
	Total	270.36	292			
Understand when writing	Between Groups	.95	4	.35	.47	.76
	Within Groups	213.74	288	.74		
	Total	214.69	292			
More writing would help	Between Groups	5.96	4	.33	.55	.70
	Within Groups	167.92	288	.60		
	Total	173.87	292			
Prefer a math class with writing	Between Groups	3.04	4	.11	.19	.94
	Within Groups	163.03	288	.58		
	Total	166.08	292			

Summary of Findings for Research Sub-question 1B.

A one-way ANOVA was performed to examine six variables and the students' letter grade in their math class at the time the survey was administered. Each variable is discussed separately.

1. Writing in math class: The analysis of variance performed on writing in math class and the students' math letter grade yielded a p value of .91. Since $p > \alpha$, the null hypothesis was not rejected. This result indicates that there is no statistically significant difference among students obtaining different letter grades in math class and writing in math class. Since there is no significant difference, there is no need for a post hoc test.

2. Enjoy writing in math class: The analysis of variance performed on enjoy writing in math class and the students' math letter grade yielded a p value of .73. Since $p > ά$, the null hypothesis was not rejected. This result indicates that there is no significant difference among students in different levels of math classes and their enjoyment of writing in math class. Since there is no significant difference, there is no need for a post hoc test.

3. Enjoy writing in other classes: The analysis of variance performed on enjoy writing in other classes and the students' math letter grade yielded a p value of .82. Since $p > ά$, the null hypothesis was not rejected. This result indicates that there is no significant difference among students with different math letter grades and their enjoyment of writing in other classes. Since there is no significant difference, there is no need for a post hoc test.

4. Understand when writing: The analysis of variance performed on understanding when writing in math class and the students' math letter grade yielded a p value of .76. Since $p > \alpha$, the null hypothesis was not rejected. This result indicates that there is no significant difference among students with different letter grades and their understanding when writing in math class. Since there is no significant difference, there is no need for a post hoc test.

5. More writing would help: The analysis of variance performed on more writing would help in math class and the students' math letter grade yielded a p value of .70. Since $p > \alpha$, the null hypothesis was not rejected. This result indicates that there is no significant difference among students with different letter grades and their feeling that more writing would help. Since there is no significant difference, there is no need for a post hoc test.

6. Prefer a math class with writing: The analysis of variance performed on prefer a math class with writing and the students' math letter grade yielded a p value of .94. Since $p > \alpha$, the null hypothesis was not rejected. This result indicates that there is no significant difference among students in different levels of math classes and their enjoyment of writing in other classes. Since there is no significant difference, there is no need for a post hoc test.

Six variables were selected to address Research Sub-question 1B, namely, students writing in math class, students' enjoyment of writing in math class, students' enjoyment of writing in other classes, students' understanding when they write, more writing would help with math, and prefer a class with writing. Students' mathematics letter grade was also reported using 5 categories: A, B, C, D, and F.

Using SPSS, a one-way ANOVA of the responses was computed for each variable to determine the p-probability. For comparison an accepted alpha of 0.05 was used for each variable to decide to reject or maintain the null hypothesis. Based on this one-way ANOVA the following conclusions about levels of mathematics and attitudes towards writing in mathematics class can be made. All six null hypotheses made were maintained based on data collected. No statistically significant differences were found between the grades maintained by the students and the variables; writing in math class, students' enjoyment of writing math class, students' enjoyment of writing in other classes, students' understanding when they write, students' feeling that more writing would help, and students' preferring a class with writing.

Since none of the null hypothesis were rejected there seems to be sufficient evidence to conclude that the letter grades students earned do not influence their attitudes

towards writing in mathematics class. In addition, for two variables, more writing would help and prefer a class with writing, all students responded close to the 2.5 acceptable favorable response mark. On closer examination of the mean data represented in table 7, the more positive response rates for all six variables came from students with lower grades (C, D, and F).

Based on the results of the one-way ANOVA performed it can be concluded that students had a generally positive attitude towards writing in mathematics classes. This was particularly evident among students who were struggling with mathematics. Students with lower letter grades (C, D, and F) indicated that they were much more in favor of mathematics classes that use writing. These students also indicated they would be more willing to seek out such classes in the future. The students with lower letter grades stated that they understood the mathematics better when they had an opportunity to write about the concepts and that they particularly enjoyed writing in other classes.

Students with naturally strong math skills may not need to write as much to learn and so did not respond as highly. Teachers are less likely to be worried about strong math students. It is low achievers who are likely to be of concern to teachers. And teachers may mistakenly fear that students doing poorly might resist new teaching techniques. Instead, these students with lower abilities, as reflected in their grades, seemed to welcome the writing methods indicating a positive opportunity for teachers looking for ways to improve student performance. Thus the data seemed to encourage the use of writing for teaching students with weaker mathematic abilities.

Research Question Two: Indications of Mathematical Knowledge Growth

Research Question 2 was: "What indications of mathematical knowledge growth and learner development can be found in student writing for mathematics classes?" Research Question 2 was further divided into two sub questions:

2.A How does the activity of writing change students' approach to preparing for tests and quizzes?

To address this question, students were asked an open-ended question at the end of the survey on how they feel writing helps them prepare for tests and quizzes. All of the open-ended questions were transcribed. The researcher then analyzed the transcripts and looked for common themes among the responses. Responses from the female and male students were kept separate.

<u>Female Students' Open-ended Responses on Writing in Mathematics Class</u>

The first open-ended question asked students to describe how writing changed the work they did for a math quiz or test. Forty percent of the female students who responded to this question stated that writing helped them understand the material better. They said this writing had a direct result on their preparation for tests and quizzes. Several students elaborated on why they felt writing gave them a better understanding. Some of these reasons were:

- By writing it helped me understand because I took it slowly, one step at a time.
- I could remember what I wrote and applied it to solving a test question.
- It is harder to explain things when I have to write it out, but since it is challenging I understand it more.
- Writing activities let you know how important it is to pay attention to questions and your answers. I didn't read a question carefully enough.
- Writing activities helped me practice in as much detail as I can for my test.

In addition to stating how writing helped in their preparation for tests and quizzes students also discussed how writing helped them learn math in general. Thirty-three

percent of the female respondents stated that helped them understand math better. Some of the reasons listed for writing helping with understanding were:

- Writing helps you understand better cause a lot of the time it helps you relate to the real world
- It helps because it explains some tougher parts of the chapter
- It just makes you think about the things more. It gets in your head
- You have to really think about each step and why you do each step

When the students were asked why they thought was important about using writing to learn math was important 63% of the female respondents again stressed the importance of writing to help in the understanding of math. The reasons given included:

- It is another way of learning it (math). Some people might be better at writing and learn math better.
- It also allows me to understand where I made my mistakes.
- If we didn't write then how can we learn? If we didn't write then how could we go back over our notes?
- To write down lessons and examples to help you when you get stuck on something.
- It goes further in depth.
- I guess it helps me to review what I've learned because most of the writing involves explaining how to solve something.

This qualitative data seems to support the statistical data about the positive value of using writing as a tool for learning math.

Male Students Open-ended Responses on Writing in Mathematics Class

When asked to describe how writing activities changed the work they did for a test or quiz, twenty-four percent of male students responded that writing helped them understand the material better. The following are typical responses from male students:

- I really didn't understand until I did the writing activity and then I did good on a quiz.
- It made me understand the material more and when we would have to use it.
- A writing activity helped me because I might have done something wrong and the writing helped me.
- It helped me understand the concept more.

Thirteen percent of male students mentioned that writing required them to think more about the mathematics and the concepts they were studying. These students also mentioned that writing forced them to practice the individual steps towards solving a problem. Writing for male students seemed to be a way of catching or preventing mistakes that might have occurred in their work otherwise. Here are some of their comments:

- I had to think a lot more than I would have if it was just strictly math.
- It helped me think things through better and I realized that I needed to think things through better.
- It made me think through the steps differently.
- I had to think in more detail.

When responding to how writing has changed the way they prepared for tests and quizzes 46% of the male students stressed that writing helps them understand the mathematics material better. Male students also mentioned that writing gave them different options for solving mathematics problems. Like the female students, the male students also mentioned that writing allowed them to see practical applications of math to the real world:

- It makes me understand when we will use math in real life.
- It has opened me to more options in doing things.
- It helps you learn different possibilities for a problem.
- It helped me look at a problem and read it carefully.
- Writing made math easier.

When asked what they thought was important about using writing to learn math, 27% of male students discussed that writing helps them understand the math concepts better. Male students also mentioned that writing allowed them to see the practical applications of math and also is another way of looking at math:

- When you write you use more than just one or two sections of your brain, same with algebra, if you combine the two, you will learn more.

- It makes you see when you will really use math.
- We need a variety of ways to learn math. If it was the same all the time, it would be really boring.
- I think by reading your answer, you understand better. Sometimes plain numbers are hard to understand.

2. B. What evidence of mathematics knowledge growth can be found in samples of students' writing for mathematics classes?

In order to answer this question, students were asked to submit samples of the writing they produced in their mathematics class. After reading through all of the assignment prompts and the students written responses, the samples of writing were divided into four broad categories. These categories were:

- Written responses to open-ended questions students did to prepare for the Pennsylvania System of School Assessment (PSSA).
- Writing that summarized a unit or a chapter covered in class.
- Writing that dealt with one particular concept being covered in a lesson.
- Expressive writing which included poetry, persuasive essays on the subject, and reflections on students learning processes.

<u>Open-ended written responses</u>

Many students submitted their open-ended written responses to practice prompts for the PSSA. PSSA as standardized subject assessments usually held in March or April. In these open-ended prompts, the students are asked two things. First, they are asked to show or describe each step of their work. Second, they are asked to write an explanation stating the mathematical reason(s) behind their work. (See Appendix D for a sample PSSA prompt.)

Forty percent of the students who submitted these as sample of writing used what is called a "T-table" to display their answers. On the left-hand side of the T, the students showed the math work they performed to solve the problem. Then on the right-hand side

the students wrote their explanation. Often times the work was divided into parts and each part was numbered and then each numbered part was explained in the right hand column (See Table 13).

Table 13

Example of T-Table Students Used to Write Explanations to PSSA Open-ended Questions.

Work	Explanation
1. $40 \times 60 = 2400$	1. You must find the area of the entire rectangle. This is found by multiplying the length by the width.
2. $2400 - 2040 = 360$	2. Next, you need to find the total area filled by cement. Since you know the total and know how much is grass, simply subtract.
3. $a = 2b$ $a + b = 360$	3. This equation will be needed to get rid of the a variable (you can't solve an equation with two variables). The second equation is found because the two different rectangles of cement added together equal the total cement.
4. $2b + b = 360$ $3b = 360$ $B = 120\ ft^2$	4. Solve the equation for b using substitution, addition, and division.
5. $a = 2(120)$ $A = 240\ ft^2$	5. Plug 120 in for b in either equation.

It can be seen from the right-hand side of the table that the writing is used to demonstrate the students understanding of the mathematical concepts being assessed. For example, in the first section the student has explained how to find area (multiply length by width). Parts 3 and 4 together demonstrate that the student understands solving systems of equations –needing two equations when you have two variables and then explaining each step of the solving equation process.

Students who did not use the "T-table" model for solving and writing their explanations tended to separate the page into two sections. The top half of the page was used by the students for their mathematical calculations. The bottom half had the written explanation. These students' written explanations tended to be more narrative in form.

> First, I multiplied 40 ft by 60 ft because that is how you find the area of a rectangle ($l \times w$). Next, I subtracted 2040 from 2400 because they said that was the area of the grass. The grass area and the concrete area should equal the total area of the courtyard. Therefore, the total concrete area is 360 square feet. Finally I did $2x + x = 360$ so that I could find the area of pad A and pad B.

While these are just two examples from over 120 samples of open-ended writing prompts that were analyzed, these samples are a good representation of one type of writing that is commonly used in mathematics classes: explanatory writing. In these explanatory writings students tended to use words such as "because," "since," "therefore," and "to find" in their writings to demonstrate understanding. While the right answer on the mathematics side of the problem may have shown that the student could solve the problem, the writing enabled the teacher to see that the students had an understanding of the concepts behind the mathematical problems being studied.

Writing that summarized a unit or chapter

The second most common pieces of writing submitted which showed growth in the students' mathematical knowledge was writing that summarized several lessons. Twenty-eight percent of the students who submitted a writing sample included a summary paragraph of a unit or chapter. For instance, one writing prompt included with a students' submitted writing sample asked the students to explain each of the three ways to solve systems of equations (see Appendix E). In response to this prompt the student explained each of the three methods and then also states which method was their favorite

and why. The students then solved one system of equation using their favorite method. The prompt also explained that students could solve two other systems using the alternate methods for bonus points something this student had done.

This type of writing assignment allowed students to go back over a particular unit and then in writing show their understanding of the unit's concepts. In the open-ended questions at the end of the survey, these writings tended to be the ones the students described as allowing them the opportunity to gain an understanding of a particular unit or chapter they were working on. Here is an example of this type of writing submitted by one of the participants:

> For graphing, you get the y on its own. Then plot the graph using the y-intercept and the slope. The solution to the system of equations is where the two lines intersect each other. If the lines do not intersect, they are parallel. That means there is no solution to the system of equations. In substitution, you get one of the variables by itself. Then plug the expression into the other equation and solving for one variable. Last find the other variable by plugging in the number for the variable you solved. In elimination, you have to get the equation in standard form. Get the coefficient of one variable to be the same by multiplying it (them). Add if the signs are the same, subtract it they are different. Once you have found one variable, then plug it in and find the other. Elimination is my favorite because I found it the easiest. Graphing is confusing because of the slope and substitution is difficult because I have trouble getting the variables by themselves.

While the concepts described in this paragraph may have taken a week for the teacher to cover, this particular assignment benefits the student because they have summarized a week's worth of work into one paragraph. When it comes time to review for a test or quiz on this material, the student can then read through this written material to refresh their knowledge. It is also beneficial for the teacher because as the student is describing their favorite method, the student is doing so by pointing out the difficulties they had with the other two methods. The teacher can use this written summary to change lessons given about the alternate methods.

The second example of writing students submitted that fell into this category dealt with graphing quadratic functions. In the prompt (Appendix F) students were asked to compare two quadratic equations by writing generalizations to a friend. Some of the students addressed each of the points mentioned, writing paragraphs to explain each of the terms in their own words:

> The role of "a" is that if "a" is positive the vertex will be the minimum of the graph and the graph will open upward. The minimum is the lowest point on the graph. The vertex is where the graph changes direction. If "a" is negative, the vertex will be the maximum of the graph and the graph will open downward. "C" is the y-intercept. It is where the graph crosses the y-axis. In each of these cases, "c" is also the vertex.

Many students also included a well-labeled graph to go with this explanation. Each of the parts mentioned above would be pointed out in the graph. So the writing activity seemed to reinforce other mathematics work by the student.

Writing that deals with a particular concept in math

Throughout the school year several of the teachers in the study gave short writing activities to the students that were not part of preparing for PSSAs or reviewing a major unit or chapter. Fifteen percent of the students in the open-ended responses listed a specific mathematics writing activity that they enjoyed doing. These included Wheel of Theodorus, Checkerboard, and Mathography to name a few. While nobody included an example of the Wheel of Theodorus, several students did include the checkerboard problem and examples of their Mathographies. The Mathography was a paragraph students had to write near the beginning of the school year where they would discuss their mathematics learning goals and expectations for the coming school year. In many cases, the students mentioned their previous math experiences and how they as students

were planning to approach this coming year. Students also discussed some of the places they currently used mathematics outside of school.

In the checkerboard problem the students had to find the total number of squares on a checkerboard(Appendix G). In the checkerboard problem, students had to write an explanation to describe how they would go about solving the problem. Many students seemed to realize that the answer to this problem was not an obvious answer of 81 little squares + one big one (the checkerboard was a 9×9). By taking the time to slow down and write out an explanation, the students appeared to have thought about other solutions. So students wrote about possible alternative solutions like 2×2, 3×3, and so on.

Expressive Writing: Poetry, persuasive essays on the subject, and reflections

Several students submitted a poem they wrote at the end of a semester which used mathematical terms they studied throughout the year. In the prompt (Appendix H), students were given a list of 30 words and they were asked to put 15 of them in a poem. The poem could be about any subject. Here is a poem one student submitted:

A **Dividing** Friendship

My friend isn't being very **rational**
The **probability** of us being friends after this fight is about **zero**
She is so **mean** all the time
Her **expressions** when we talk are dull and boring

I am trying to **function** all of this in my head
But my thinking **mode** is coming to an end.
I am trying to gain the **power** to talk to her
But I can't seem to find a reason why

I don't think this **combination** is going to work anymore
I am going to miss Friday nights when we watch the **Matrix**
But we can't seem to stand each other
Our friendship is definitely **sloping** down hill from here

We are like a pair of **opposite angles**

I'm **positive** and she is **negative**
I keep trying to **substitute** our **problems** with other problems
But every time I think about them I **add more**

Our friendship is a **binomial** that can no longer be **factored**
But I will try to be nice and make things **equal**
But they might not end up with a **solution**
I know I can try though.

This activity seems to have given the student an opportunity to look at the language of mathematics and explore how the words used to represent mathematical terms can have the same every day uses in other contexts. Such a language exercise can help a student consider the ways mathematical concepts can be applied to daily life.

Eight students submitted a persuasive essay they had written arguing for the value of algebra or geometry. The audience these students had in mind seemed to be future algebra or geometry students and the students were setting the stage for the importance these mathematics classes are as part of their education. In these essays, the students had to write an opening sentence and then list some facts that supported their statement. They had to finish the essay with a conclusion. All students had listed 2 or 3 uses of mathematics outside of school and developed the argument for wanting to study math.

Research Question Three: Gender and Writing in Mathematics Class

Research Question 3 asked: "How do writing tasks affect female students' learning of mathematics?" To answer this question, responses from the survey were analyzed using an independent sample t-test. Items numbered 9 through 14 on the survey addressed question 1. The following dependent variables were addressed:

Dependent Variables

- I enjoy writing in mathematics class
- 1 enjoy writing in other classes

- I understand the math concepts better if I have to write about them at the end of a unit
- A math class that uses writing activities helps you learn better than a math class that does not use writing activities.
- Doing even more writing activities in math classes would improve my
- learning/understanding.
- What role do you believe math will play in your future?
- What career would like to have?

Independent Variable:
The independent variable was gender.

Research Question 3 was further divided into two subquestions:

3. A. How does writing in a mathematics class affect female students' attitudes toward mathematics?

Null Hypothesis:

There is no significant difference between gender and students' enjoyment of writing in mathematics class.

There is no significant difference between gender and students' enjoyment of writing in other classes.

There is no significant difference between gender and students' understanding of math concepts after writing about them.

There is no significant difference between gender and students' view that writing activities helps them learn better.

There is no significant difference between gender and students' view that doing more writing activities would help them learn better.

Alternative Hypothesis

There is a significant difference between gender and students' enjoyment of writing in mathematics class.

There is a significant difference between gender and students' enjoyment of writing in other classes.

There is a significant difference between gender and students' understanding of math concepts after writing about them.

There is a significant difference between gender and students' view that writing activities helps them learn better.

There is a significant difference between gender and students' view that doing more writing activities would help them learn better.

Table 14

Summary Table of Descriptive Statistics for the Variables of Students' Gender and Attitudes Towards Writing in Mathematics Class

Variable	Math Class	N	M	SD	t
Enjoy writing in math class	Female	130	2.18	.80	.01*
	Male	163	1.94	.80	
Enjoy wring in other classes	Female	130	2.68	.96	.00**
	Male	163	2.01	.86	
Understand more when I write	Female	130	2.22	.87	.22
	Male	163	2.09	.84	
More writing would help	Female	130	2.43	.75	.08
	Male	163	2.27	.79	
Prefer a class with writing	Female	130	2.55	.75	.00**
	Male	163	2.28	.74	

$\alpha = .05$ * $p < .05$; ** $p < .01$; *** $p < .001$

Summary of Findings for Research Sub-question 3A.

An independent sample t-test was performed to examine five variables and the gender of mathematics students. Each variable is discussed separately.

1. Enjoy writing in math class: The t-test performed on enjoy writing in math class and gender of students yielded a p value of .01. Since $p < .05$, the null hypothesis was rejected. This result indicates that there is a significant difference among male and female students and their enjoyment of writing in math class.

2. Enjoy writing in other classes: The t-test performed on enjoy writing in other classes and the gender of mathematics students yielded a p value of .00. Since $p < .001$, the null hypothesis was rejected. This result indicates that there is a significant difference among male and female students and their enjoyment of writing in other classes.

3. Understand when writing: The t-test performed on understanding when writing in math class and the gender of students yielded a p value of .22. Since $p > \alpha$, the null hypothesis was not rejected. This result indicates that there is no significant difference among male and female students and their understanding when writing in math class.

4. More writing would help: The t-test performed on more writing would help in math class and the levels of mathematics students take yielded a p value of .08. Since $p > \alpha$, the null hypothesis was not rejected. This result indicates that there is no significant difference among male and female students and their view that more writing in math class would help.

5. Prefer a math class with writing: The t-test performed on prefer a math class with writing and the gender of students yielded a p value of .002. Since $p < .01$, the null hypothesis was rejected. This result indicates that there is a significant difference among students in different levels of math classes and their enjoyment of writing in other classes.

Five variables were selected to address Research Sub-question 3A, namely, students' enjoyment of writing in math class, students enjoyment of writing in other classes, understanding when they write, more writing would help with math, and prefer a class with writing. Students' gender was also reported.

Using SPSS, an independent sample t-test of the responses was computed for each variable to determine the *p*-probability. For comparison an accepted alpha of 0.05 was used for each variable to decide to reject or maintain the null hypothesis. Based on this t-test the following conclusions about the gender of students and their attitudes towards writing in mathematics class can be made. Two of the five null hypothesis made not rejected based on data collected. No statistically significant differences were found between male and female students and the variables understanding when they write and more writing would help. Three variables, however, did result in the null hypothesis being rejected. These were enjoy writing in math class, enjoy writing in other classes, and prefer a class with writing. When examining the mean data represented in Table 14, one can note that for all five variables, female students responded more positively than male students. This would seem to indicate, therefore, that female students tend to have a more positive attitude towards writing in mathematics classes.

3.B. How does writing in a mathematics class affect the future career goals of female students?

Null Hypothesis:

There is no significant difference between gender and students' beliefs that math will play a role in their future.

Alternative Hypothesis:

There is a significant difference between gender and students' beliefs that math will play a role in their future.

Table 15

Summary of Independent Sample T-Test for Variables of Students' Gender and the Role of Math in Their Future

Variable	Math Class	N	M	SD	t
Role of math in future	Female	130	2.70	.55	.78
	Male	163	2.68	.61	

Summary of Findings for Research Sub-question 3B.

A t-test was performed to examine the variables role of math in their future and the gender of mathematics students. The t-test performed on the role of math in their future and gender of students yielded a p value of .78. Since $p > \alpha$ the null hypothesis was not rejected. This result indicates that there is no significant difference among male and female students and their views of the role mathematics will have in their futures.

The students were also asked in the survey to state what career they would like to have in the future. Table 16 summarizes these results. The chosen careers have been shown for both male and female students.

Table 16

Career Choices Among Male and Female Students

Careers	**Females**	**Males**
Artist/writer	24(18%)	6(4%)
Medical Field	23(18%)	21(13%)
Sciences	12(9%)	11(7%)
Teacher	11(8%)	7(4%)
Criminology	10(8%)	3(2%)
Lawyer	7(5%)	5(3%)
Psychology	6(5%)	1(1%)
Engineer	5(4%)	14(9%)
Actor (female only)	6(5%)	
Sports (male only)		24(15%)
Business (male only)		10(6%)
Architect (male only)		7(4%)
Computers (male only)		6(4%)
Ambassador (male only)		2(1%)
Mechanic (male only)		2(1%)
Helicopter pilot (male only)		2(1%)
Other	7(5%)	9(6%)
Undecided	19(15%)	31(19%)
Total	130	163

When looking at the percentages of career choices for female and male students, the percentages are close for the careers the genders have in common except artist/writer category. For the artist/writer, 18% of female students would like to pursue a career in the arts whereas only 4 % of males gave that as their choice of career. The careers that were included in the category of other were the same for both male and female students. These careers included: military, real estate archeologist, and hotelier. Each of these had three or fewer students selecting them as a career choice by both male and female students. It should also be noted that 32% of males selected a career choice that was not mentioned by any female student. These included sports, business, computers, architect, ambassador, mechanic, and helicopter pilot. Acting was the only career that female students chose which was not mentioned by any male students. This seems to indicate that male students seem to envision a much wider range of career opportunities than female students.

Conclusion

This chapter reports on the results for each of this study's three research questions. Data for question 1 and question 3 were quantitative in nature and were analyzed using inferential statistics. Data for question 2 were qualitative and were analyzed using inductive analysis. Chapter 5 will discuss the findings of the study, offer practical recommendations for the role of writing in mathematics classroom, and make recommendations for additional research.

CHAPTER 5

FINDINGS, RESEARCH IMPLICATIONS, AND CONCLUSION

Mathematics can be found in all walks of life from the worlds of business and technology, to the sciences, to medicine, and even to environmental and management. The subject of mathematics in the schools has been called a "gateway" subject (Herzif & Knott, 2005) that opens the door to future opportunities for students. In recent years, many attempts have been made to try to improve mathematics education for students (Steen 2003). However, too many students still fail to succeed in mathematics or, even if they do succeed, they fail to see the value and uses of mathematics outside of the mathematics classroom.

As discussed in chapter two there is some research on the value of writing in mathematics classes (Baxter, Woodward, & Olson 2005; Gibson & Thomas, 2005; Miller, 1992, Ntenza, 2006; O'Connell Beamon, Beyea, Denvir, Dowdall, Friedland, & Ward, 2005; Shield & Galbraith, 1998). However, despite these claimed advantages to the use of writing for teaching mathematics, this pedagogical technique is not widely used among mathematics teachers and research on this approach has been minimal. Shield and Galbraith (1998) note that while writing for mathematical learning has received some attention in the research literature, not much is known about the benefits of this approach and no descriptive studies have been made of the actual types of writing that are used in mathematics classrooms.

The present study has addressed the issue of using writing as a teaching tool in the mathematics classroom as a way of engaging students more actively in their own learning. This study examined student perceptions of how the use of writing in

mathematics classrooms impacted student learning in a high-stakes testing climate. In addition to looking at students' perceptions and attitudes towards writing in mathematics classes, emphasis was placed on how gender plays a role in shaping those perceptions. An examination was also done of the different types of writing that are currently taking in place in mathematics classrooms that use writing as a teaching tool.

This study aimed to answer three main research questions:

1. How do writing activities affect students' attitudes toward learning mathematics?
2. What indications of mathematical knowledge growth and learner development can be found in student writing for mathematics classes?
3. How do writing tasks affect female students' learning of mathematics?

This chapter summarizes and discusses the findings of the study, offers practical recommendations for using writing in the mathematics classroom, and makes recommendations for further investigation related to writing in the mathematics classroom.

Summary of Study

This study examined the use of writing as a teaching and learning tool in mathematics classrooms of several sixth, seventh, and eighth grade classes in Western Pennsylvania. Specifically, the study explored students' attitudes towards writing in a mathematics class and asked students to discuss the ways they felt writing impacted their learning of mathematics. Results of this study identified (a) students' attitudes towards writing in a mathematics class, (b) evidence of mathematical knowledge growth found in

students' writings, and (c) the difference between male and female students' attitudes towards writing in mathematics class.

Data were collected in spring 2007 from students who had spent the better part of a school year with a mathematics teacher who regularly used writing as a teaching tool. Quantitative data were collected using a researcher-designed survey (Appendix A). Questions utilized on the survey corresponded to the three primary research questions as well as sub-questions. Demographic information gathered and utilized included grade level (sixth, seventh, or eighth), current mathematics letter grade (A, B, C, D, or F), career plans, and gender. Open-ended questions and samples of students' writing provided qualitative data to clarify and enrich the quantitative results.

The qualitative responses of the participants in the study indicated a positive attitude among students who participated in the study toward writing as a tool for learning mathematics. Based on the results of the one-way ANOVA performed on the quantitative data, it can also be concluded that students have a positive attitude towards writing in the mathematics class. These attitudes were particularly high among students who received lower letter grades in mathematics (C or below). In terms of gender of students and their attitudes towards writing in mathematics class there is also an indication that female students tend to have a more positive attitude towards writing in mathematics classes than their male counterparts.

Discussion

Research Question 1

How Do Writing Activities Affect Students' Attitudes Toward Learning Mathematics?

With respect to writing activities affecting students' attitudes toward learning mathematics, the results were mixed. When comparing students in different mathematics classes (Math 7, Pre-Algebra, Algebra, and Geometry), students were not overly positive about the value of writing in mathematics class. A mean of 2.5 or higher indicated a positive result. However, for all the variables examined, none received a mean of 2.5 or higher but several were in the 2.0 to 2.4 range, indicating that some students did agree with the statements:

- I often have to write in mathematics classes.
- I enjoy writing in mathematics class
- I enjoy writing in other classes.
- I understand the math concepts better if I have to write about them at the end of a unit.
- A math class that uses writing activities helps you learn better than a math class that does not use writing activities.
- Doing even more writing activities in math classes would improve my learning/understanding.

It should be noted, however, that students in pre-algebra consistently were more positive towards writing in a math class than students in any other mathematics class. One of the reasons for this may have been that the majority of the pre-algebra students were in seventh grade and this was the first time where they were taught by a different teacher for each individual subject. Seventh grade students not that far removed from their elementary school days where one teacher would have taught them language arts and math. Thus, it seems reasonable to expect younger students to be the least opposed to having a math teacher suggest they write about a concept or topic in mathematics class as

the data shows. In their K-6 classes, students might see writing and mathematics in close proximity. Students in upper grades are more likely to have experienced more subject isolation, with mathematics being taught without any writing activities.

Steele and Johanning (2004) discuss the importance for pre-algebra teachers to break away from the traditional algebra curriculum. They "examined whether pre-algebra students effectively learn to express their algebraic thinking in ways different from the traditional algebra curriculum" (p. 65). The 7th grade pre-algebra students in Steele and Johanning's study were using schema to store, synthesize, generalize, and mentally retrieve similar experiences when solving problems. The findings in this study would certainly support that of Steele and Johanning's in that when students are allowed to write as a means of organizing information, these students tend to gain a better understanding and are better prepared for the next level of mathematics study. According to Steele (2005), reporting on the same study referenced above, having students explain their approaches in writing helped students make sense out of the mathematics they were learning. The present study appears to support this, at least for students at the pre-algebra grade level.

A comment needs to be made about Math 7 students at this point. Like the majority of pre-algebra students all Math 7 students were seventh graders. However, this group of students were not as positive as their counterparts in pre-algebra. One of the reasons for this may have been that Math 7 students overall are not as strong mathematically as the pre-algebra students. As a result, because these students have struggled with mathematics throughout their schooling so far, they may not see writing as having any benefit to their learning. The results of this study however, could be used to

help Math 7 teachers see the benefits in using writing in these classrooms and a tool for teaching mathematics.

When comparing students of different abilities by looking at grade levels, the study indicated that students with lower letter grades (C, D, and F) tended to have more positive attitude' toward writing in mathematics class than those with higher letter grades (A and B). Students with grades of C, D, or F also stated that they would be more willing to seek out mathematics classes that used writing when deciding on a mathematics class to take in the future. This is not uncommon according to Frost, Marten, Lahart, and Rosenblate, (1990). Frost, Marten, Lahart, and Rosenblate found that when it came to writing, many mathematically talented students had difficulty with writing activities. Some of this may stem from these strong mathematics' students quest for perfectionism. To these skilled students, writing may appear to be too great a diversion from the more abstract elements of mathematics reasoning.

The results of this study would therefore indicate that writing in mathematics classes would be beneficial to low level students. For many of these students they may have had poor past experiences with mathematics and so writing would be a change that could lead to some positive results. While teachers are less likely to be worried about strong math students and so spend time trying to come up with ways to help weaker students. According to Gardner (1993) one of the purposes of school is to help students develop intelligences and that all intelligences should work together to solve problems. "Not all people have the same interests and abilities, and not all of us learn in the same way" (p. 10). In other words, while every writing activity assigned might now work for

every student, teachers of all mathematics levels and abilities should see the benefits of using writing as a teaching tool when other options do not appear to be working.

According to this study, writing activities do affect students' attitudes toward learning mathematics. Seventh grade pre-algebra students seem to be most in favor of mathematics classes that use writing. Students with lower ability in mathematics as determined by math letter grade also seemed to enjoy the opportunity to write in mathematics classes.

Research Question 2

What Indications of Mathematical Knowledge Growth and Learner Development Can Be Found in Student Writing for Mathematics Classes?

Analysis of the answers to the open-ended questions at the end of the survey and the samples of students' writings provided evidence of students' mathematical knowledge growth and learner development. Evidence of mathematical knowledge growth could be seen in the different types of writing assignments the students submitted. In the open-ended questions at the end of the survey, the students wrote about the ways writing helped them prepare for tests and quizzes. Many students felt that writing slowed them down and as a result they were able to focus more on their work and understood the mathematical concepts better. Male students tended to be the group that responded more often in favor of writing slowing them down and so they did not make all the little mistakes they were inclined to make without writing. All students discussed the importance of writing to help with the understanding of mathematics and several mention the real world applications writing allowed them to make with mathematics.

There were several different types of writing submitted. The most common type of writing sample submitted were practice prompts students did to prepare for the Pennsylvania System of School Assessment (PSSA). The likely reason for this is that, all students in the study, regardless of grade level or mathematics course, were required to has to take the PSSA test in March or April. As part of the PSSA mathematics assessment, students are required to answer 3 to 5 open-ended questions. For these questions a mathematics problem must be solved and a student must provide a written explanation of the way they solved the problem. Even if a mathematics teacher does not use writing regularly in their mathematics class, most Pennsylvania mathematics teachers do work to prepare students for these open-ended prompts, which require written explanations. These written explanations give evidence of the student thinking behind the processes students used to solve a mathematics problem.

The second most common types of writing sample were summary type assignments that students did at the end of a unit. These writings allowed the students to review a unit's concepts and make comparisons or contrasts between sections or in some cases state preferences for one problem solving method over another. Reading through these summary writings, there was evidence of students' mathematical knowledge growth. Students were given the opportunity to point out the difficulties they were having with a particular lesson or unit without demonstrating this by failing to correctly answer a question about a topic on a test or quiz. It was also evident in the student writings that by having to write about a unit, this allowed them to make sense of the mathematics (Steele, 2005). As the following student quote states: "Writing makes you go further into a problem you are trying to solve and it helps you to understand better. It helps bring the

point home." This and similar statements showed that the act of writing unit summaries caused students to consider just what concepts they had learned and how well they understood these concepts. This type of writing appeared to develop the students' ability monitor their own learning processes.

Some of the most important findings came when looking at the results of the quantitative data and qualitative data together. When completing the survey, most students indicated that they disagree or strongly disagree with the statement I enjoy writing in mathematics class. However, when it came to the open-ended questions at the end of the survey, most students described a large range of benefits from writing in mathematics and talked positively about the activity's value when they were asked to state what is important about using writing to learn mathematics. Ninety percent of the students who answered this question gave a positive response as to why they thought using writing to learn math was important. Some of the most common responses pertained to writing helping with understanding, to writing allowing you to think in more depth, and to writing making math more interesting. One student went so far as to point out that important learning comes from reading your answer to help you understand. This student finished this response by stating, "Sometimes plain numbers are just hard to understand."

Thus while quantitative data might have shown a negative student view of writing in mathematics class, the quantitative view offered a more positive view. The explanation for this difference is likely that students may at first impression think writing doesn't help them learn mathematics better. Therefore, most students say they disliked writing in mathematics class. But when asked to discuss in detail how the writing tasks helped them

learn, the students recalled the value of those writing activities. Perhaps if the students had been asked the open-ended questions first, they would have been more likely to offer a positive view of writing on the quantitative survey questions.

In summary, the answer to research question 2 is that there is indeed evidence of students' mathematical knowledge growth in the students' writings. In their responses to the open-ended survey questions, the students gave detailed explanations of how their approach to mathematics learning and their understanding of mathematical concepts had changed and improved as a result of performing the various writing tasks in their classes. In addition to the survey responses, the students' writing samples showed how the students were learning to use writing to explore alternative solutions to problems and also to check and reflect on their understanding of the new mathematical concepts they were being taught.

Research Question 3

How Do Writing Tasks Affect Female Students' Learning of Mathematics?

With respect to gender and writing in the mathematics classroom, there was clear evidence that females responded more favorably than their male counterparts towards writing in mathematics class. When it came to enjoying writing in math class and preferring a math class that had writing, females were more favorable in their responses to these survey items than their male counterparts. Additionally, in the open-ended survey response questions female students also tended to give much more elaborate answers than the male students about how useful they found writing in mathematics class and what they learned from doing this writing. These more in depth open-ended survey responses would seem to indicate that the female students felt more positively than their male

counterparts about how much writing improved their understanding of the concepts they were learning about in mathematics. Based on the type and length of the female students' responses to the open-ended survey questions, these female students appeared to be highly verbal and very effective writers. It makes sense, then, that these female students would respond positively to mathematics classes that encouraged them to use their strong verbal skills.

One potential benefit of asking female students to write in mathematics class is that this activity helps students learn to see mathematics as a more creative subject, as a subject where words and verbal thinking can be just as valuable as numbers and analytic thinking. In a study of math anxiety, Malinsky, Ross, Pannells, and McJunkin (2006) found that a significant number of students believed the myth that "math is not creative" (p. 279) and that this erroneous belief contributed to their math anxiety problems. The present study illustrates that when female students are shown how mathematics can be made a creative subject of study through the use of writing, these female students respond favorably to the approach. Thus, the use of writing in mathematics not only can help make mathematics class more enjoyable for female students, but it might also lower these students' potential math anxiety or, at the very least, dispel the false notion too many students seem to believe that mathematics cannot be creative.

Some of the most interesting findings to the research question about how writing tasks affected female students' learning of mathematics came when comparing female and male attitudes toward writing in a mathematics class. Female students tended to respond favorably to writing in mathematics classes and explained the benefits of writing in great detail in their answers to these open-ended questions. Male students, in contrast,

were more inclined to disagree or strongly disagree in answer to survey questionsa bout whether they enjoyed writing in a mathematics class with writing. Nevertheless, even male students who said they disliked writing in mathematics class still gave very detailed written explanations of the ways writing changed how they prepared for a test or quiz, how writing changed the way they learned math, and why they thought writing was important for learning math. Like the female students, the majority of the comments written in response to the open-ended survey questions by the male students were very positive and very well written.

Mathematics teachers have long been concerned with finding ways to improve the achievement of their female students. The findings of the present study suggest a clear benefit to female mathematics students from the use of writing as a tool for learning mathematics. This lends support to the work of other researchers (Bosse & Rotigel 2006; Lamb, 1997; Orhun, 2007) who have noted female students' more verbal styles of learning. Thus, one can conclude from the data collected for the present study that efforts should be made to make writing a more widespread teaching practice in mathematics curricula throughout Pennsylvania. When it comes to the problem of helping female students succeed in mathematics classes, this study shows that writing is the solution for which mathematics teachers have been searching.

Implications

There are five major implications that should be considered based on the findings of this mixed method study of writing in mathematics classes.

Implications for Mathematics Teachers

The results of this study demonstrate a number of ways in which writing can be a successful mathematics-teaching tool. While writing has been addressed before in mathematics education research, Shield and Galbraith (1998) point out that the types of writing used have not been studied in detail. The present study provides mathematics educators with new ideas on how to use writing as a teaching tool. The results also give students' positive perceptions on the value of writing in mathematics classes. In addition, the results give a strong indication that writing is a useful way to close the achievement gap between male and female students in mathematics. This study also shows that writing is a task which can help students who struggle in mathematics. Thus this study provides strong support for the argument that mathematics teachers should make writing a regular part of their pedagogy.

Implications for Education

In this current era of high stakes testing, it is extremely important that disciplines within the academy support one another. Mathematics departments need to depend on English departments in order to reach the standards that have been set by forces beyond their control. English departments are in the same situation. All students from grades 3 through 8 are assessed every year. Students need to be able to write open-ended prompts in both reading and mathematics. In addition to this, students also need to have met multiple anchors that are assessed at each grade level. This study shows that if educators wish to effectively prepare students for these standardized assessments, it is important that teachers use writing and mathematics simultaneously. Increasing the use of writing

in mathematics can improve student performance both in class and on the standardized test.

Implications for the Field of Mathematics

While this study grew out of the need for teachers to prepare eighth grade students for the writing component of a state mathematics assessment, the findings of this study have positive implications for the field of mathematics in general. One of the difficulties higher level mathematics classes faces is the lack of female students pursuing higher level mathematics study. In order to overcome their fears, female students have to be allowed an outlet in which they can demonstrate their understanding of mathematics. This study has shown that writing can be a powerful tool for middle level female students and also those who struggle in mathematics. Therefore, the tool of writing should be used throughout middle and high school and on into higher education for the teaching of mathematics.

Implications for the Field of Writing Studies

Writing Across the Curriculum (WAC) was the initial justification used to connect writing use with mathematics teaching. This study thus has implications for the field of writing studies. WAC's main purpose was to bring writing into all content levels and to use writing as a teaching tool. This study supports WAC's mission of the marriage between writing and other content areas. The findings of this study can certainly be used by WAC proponents to encourage writing not only in mathematics but also in science, business, and other non-writing disciplines. This study shows that students perceive writing as very helpful for their learning of mathematics echoing WAC beliefs.

Implications for Mathematics Researchers

This study was aimed at adding to the research on writing in mathematics. As such it, offers several valuable contributions for other mathematics researchers. Firstly, Clark (2001) had said very little of the research on writing in mathematics focused on students' perceptions of the effectiveness of this pedagogy. The present study offers a very detailed analysis of students' perceptions. In particular, the present study shows that whether or not students say they enjoy writing in mathematics class, they do find the activity highly useful in terms of their mathematics learning. The study also shows that female students and students with lower letter grades in mathematics seem to be the ones who respond most favorably to this teaching method. Thus, researchers can take from this study that students have much of value to contribute regarding their perceptions of writing as a tool for learning mathematics. This study illustrates that students make an excellent study population, and this study will hopefully encourage other researchers to conduct studies of student perceptions of writing for learning mathematics. In light of the differences among student groups found in this study, researchers might also now find it useful to explore more carefully why distinct groups of students perceived so different writing's effectiveness for learning mathematics. Secondly, the study offers and describes a wide variety of writing activities to which mathematics students have gained exposure. These activities include: written responses to open-ended questions students did to prepare for the PSSA, writing that summarized a unit or a chapter covered in class, writing that dealt with one particular concept being covered in a lesson, expressive writing which included poetry, persuasive essays on the subject, and reflections on students learning processes.

Shield and Galbraith (1998) have argued that there is a lack of descriptive studies of the types of writing activities being used in mathematics classes. Though the present study does not offer an exhaustive description of all such activities, the study has brought to light many writing activities which mathematics researchers may wish to investigate.

Finally, this study drew results and implications from both quantitative and qualitative research data. In fact, the strength of many of the study's conclusions lie in the blending and overlap of these two types of data. In some cases, as with female students' perceptions of the benefits of writing for learning mathematics, the qualitative data corroborated the quantitative statistics. But even more interestingly, in the case of the male students, the qualitative data countered the quantitative data, showing that even though male students said they disliked writing in mathematics class, they still found it valuable. This study's findings would have been weaker if they had been based on only one type of data. Instead, the present study shows that a mixed-method research approach can be a highly useful approach for certain kinds of research topics. Therefore this study lend support to the larger arguments being advanced by Curlette (2006) and others in support of mixed-method research.

Limitations of the Study

The results of this study are not without limitations. One limitation to this study is that survey questions, open-ended questions and samples of student writings involved collection of data from a particular type of mathematics teacher. The teachers who volunteered their classes for this study were teachers who frequently used writing as part of their mathematics class. The success of writing as a tool for teaching mathematics may be dependent on having an educator who believes in the power of writing as a learning

tool. Unfortunately, being able to use writing as a teaching tool may not be a strength for many mathematics teachers. As a result, it may not be easy to generalize these results to all mathematics classes. Still this study does lend support to those mathematics teachers already using writing. More importantly given the many benefits for teaching mathematics with writing which this study shows, the study will hopefully encourage many more mathematics teachers to try adding some words to their numerical pedagogies.

Future Research

The present study has provided a detailed look at student perceptions of writing as a tool for learning mathematics in three teachers' classes. Yet this research is still clearly only a beginning point. As a follow-up to the present study, I plan next to look more closely at the role of writing as a tool for assessment in mathematics classrooms. Specifically, given the value of writing activities for learning mathematics revealed in the present study, I hope to study some mathematics classrooms where students keep mathematics portfolios which include regular writing. Such classes would hopefully offer data that could be examined for long term learning on students' parts and also for comparison with traditional achievement scores by the students.

A number of other valuable studies also naturally could follow from the present study. I call upon other scholars to study student perceptions of writing in mathematics classes at the high school level, at the collegiate level, and even, where possible, at the elementary level. There is also a need to repeat the present study in other Pennsylvania schools and in other states across the nation. It would also be highly valuable to have some longitudinal studies conducted where students exposed to writing in mathematics

classes where followed over a period of years to see not only how their mathematics achievement progressed but ultimately what sort of college majors or careers these students pursued, especially female students.

In addition to looking at student perceptions, qualitative interviews of mathematics teachers who use writing as a pedagogical tool would likely yield a wealth of information about how writing tasks can be integrated successfully into mathematics curricula. Such qualitative research would certainly lead to the collection of valuable archival materials such as lesson plans, assignments, and assessment rubrics, all of which would be helpful to disseminate to interested mathematics teachers.

Finally, some useful research could certainly be done on those students who resist the idea of using writing to learn mathematics, particularly high achieving mathematics students who dislike writing. Interviewing these students would be a useful way to find out both why the students dislike the writing activities and how those activities might be reshaped to make them more valuable for both high level and low level mathematics students. Of course interviews with students who enjoy writing in mathematics class would also doubtless prove quite interesting as a way of learning what elements of writing seem the most effective for helping students.

Given the success of the present study, I hope that the area of writing and mathematics will provide a rich research agenda not only for myself as a scholar, but also for many other mathematics researchers in the years to come.

Final Thoughts

This study is important because it provides a tool for teachers who are searching for ways to improve the mathematics performance of female students and students who struggle with mathematics. What can be seem from this study is that though students may say they do not enjoy writing in mathematics class, yet these students still see many benefits from using writing to learn mathematics. One of the main benefits students describe is that writing helps them understand mathematics concepts better. It is hoped, then, that because writing helps the students gain a better understanding of mathematics, then the students will be able to perform better as they progress through higher level mathematics classes.

There were several things I learned from conducting this study. First, I learned the importance of talking and asking students for their input into their education. So much of the literature on teaching and learning focuses on how teachers perceive what is happening in the classroom. Yet the students are the ones who make up the classroom. Without them, there would be no classroom. Teachers should work harder to get input from their students as the students can be a valuable source of feedback about the learning that is occurring.

Second, I learned a wide variety of ways in which writing can be incorporated into the a mathematics class. Writing a response to an open-ended prompt for a standardized test is only one form of mathematics writing. Other ways of writing in a mathematics class include persuasive essays, reflective writing and even poetry.

Third, I learned how to conduct research. This project has given me an opportunity to select a topic, do a literature review, design a survey, pilot the survey, find

subjects willing to participate in my study, collect and analyze both quantitative and qualitative data, and discuss the findings. As I begin my career as a college mathematics education professor, I believe the work I have done on this dissertation project has prepared me to pursue an active research agenda exploring writing and mathematics. I feel I've gained a foundation in research practice which will enable me to make a contribution to the field. The lesson I will take with me is how important research is in our teaching and interaction with others.

Finally, as I draw this study to a close, I'm reminded of this quote from Ian Stewart, a professor of mathematics and director of the Mathematics Awareness Center at the University of Warwick, England (2006):

> To my mind, the most important feature of good teachers is that they put themselves in the student's position. It's not just a matter of giving clear and accurate lectures and grading tests; the main objective is to help the student understand the material. Whether you are delivering a lecture or talking with students during office hours, you have to remember that what seems perfectly obvious and transparent to you may be mysterious and opaque to someone who has not encountered the material before. (p. 160)

As educators, it is critical for us to remember that the most important part of our work is students and we have to make sure we examine every avenue to help them learn. It is my hope that this study and the use of writing to teach mathematics become one such avenue for my fellow teachers.

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APPENDICES

Appendix A: Mathematics Class Survey

This survey is designed to help the researcher gain some insight on how effective various aspects of your math classes are for you as a student. You are being asked to evaluate which methods you feel are the best for learning math. Your responses will help math teachers improve the math curriculum in order to enhance students' learning experiences.

Please answer all items as completely and honestly as you can.

Please circle the letter that best describes your feeling about the statement.

	Strongly Agree (SA)	**Agree (A)**	**Disagree (D)**	**Strongly Disagree (SD)**
Mathematics in General				
1. Math is a challenging subject	SA	A	D	SD
2. I work to the best of my ability in math class	SA	A	D	SD
3. Math homework helps me better understand math concepts	SA	A	D	SD
4. I find the material in my math class difficult	SA	A	D	SD
5. I like working in pairs/groups	SA	A	D	SD
6. The math grade I earn reflects my efforts	SA	A	D	SD
7. I enjoy math class	SA	A	D	SD
8. I am nervous about the next math class I have to take	SA	A	D	SD

	Strongly Agree (SA)	**Agree (A)**	**Disagree (D)**	**Strongly Disagree (SD)**
Writing in Math Class				
9. I often have to write in mathematics classes	SA	A	D	SD
10. I enjoy writing in mathematics class	SA	A	D	SD
11. 1 enjoy writing in other classes	SA	A	D	SD
12. I understand math concepts better if I have to write about them at the end of a unit	SA	A	D	SD
13. A math class that uses writing activities helps me learn better than a math class that does not	SA	A	D	SD

use writing activities

14. Doing even more writing activities in math classes would improve my learning/understanding	SA	A	D	SD

	Strongly Agree (SA)	**Agree (A)**	**Disagree (D)**	**Strongly Disagree (SD)**
Math Teacher				
15. My math teacher enjoys teaching	SA	A	D	SD
16. My math teacher is available and willing to help me	SA	A	D	SD
17. My math teacher uses a variety of activities to help me learn	SA	A	D	SD
18. It helps if my teacher explains a practical application of the concept we are studying	SA	A	D	SD
19. My teacher believes that writing activities help me learn math	SA	A	D	SD
20. My teacher explains how the writing activities are related to math concepts	SA	A	D	SD

Please circle the word that best describes your answer to the question.

21. My teacher checks my math homework	always	sometimes	never
22. My teacher writes comments on my homework	always	sometimes	never
23. I leave my math classroom feeling like I understood the lesson	always	sometimes	never
24. Some of my math homework involves writing activities	always	sometimes	never

Please circle one.

25. What role do you believe math will play your future?	A large role	A small role	No role
26. How much time do you spend on math homework each night?	0-30 mins	31 mins – 1 hr	over 1 hour

27. Name one math concept you would like to learn better _____

28. Name one way you could improve your learning of math _____
(do more writing about math, spend more time on homework, spend more time studying for tests/quizzes, etc.)

Open-ended Questions

Please answer these questions in as much detail as possible.

29. Describe how some writing activity changed the work you did for a math quiz or test.

30. Describe in detail one writing activity you have done for math class.

31. List some of the other types of writing activities you have done for math class.

32. How has writing changed the way you learn math?

33. What do you think is important about using writing to learn math?

Demographic Information

34. Gender (Circle One) Male Female

35. Plans after high school 4 year college 2 year college get a job undecided

36. What career would you like to have? _____

37. Current math class _____

38. Grade level _____

39. Current math grade A B C D F

40. Favorite school subject _____

Thank you very much for your help in filling out this survey.

Appendix B: Informed Consent Letter

A Research Project Invitation
For Students and Parents
Informed Consent Letter for
Writing to Learn Mathematics: A Mixed-Method Study

Dear Student and Parent/Guardian,

My name is Edel Reilly and I am a math teacher in a middle school. I am also a student at Indiana University of Pennsylvania and I need to conduct a research project as part of my dissertation work. The purpose of my study is to examine the effectiveness of writing in mathematics classes. The goal of my study is to gather information from students about how they think using writing impacts their learning of math. I would really like you to help me out by participating in my study. If you have any questions about my study or what you will need to do, my email and phone number are at the end of this letter.

You were chosen to participate in this study because you currently do writing in your math class. This study is designed to provide information on how to improve math teaching through the use of writing. Your participation in this study is very important. Participating in this study is entirely voluntary. **You are under no obligation to take part in this study. It is also important for you to know that your grade will not be impacted in any way whether or not you choose to participate in this study.** You are free to withdraw from this study, with no questions asked. You can withdraw by contacting me by phone (724)-349-6326 or by email (e.reilly@iup.edu). You may also turn in a blank survey if you decide to withdraw on the day the surveys are administered.

A final copy of research findings from the study will be made available to anyone interested. Your teacher will also be given a copy of the findings.

What do you need to do in order to participate?

- Step 1. Fill out a survey.
  Completing this survey will take less than 30 minutes of your current math class. Your name will not appear anywhere on the survey.

- Step 2. Turn in samples of your math course work.
  After filling out the survey, I would also like you to select 1 or 2 pieces of writing from your math class to submit with your survey. These are writing samples you have already completed. You should remove or black out your name from the writing samples before turning them in.

If you are willing to participate in this study, please sign the attached **Consent Form** and return it to your math teacher before **May 25th**. **Both the student and a parent/guardian need to sign this consent form.** If you have any questions regarding this study, please contact me by email (e.reilly@iup.edu) or by phone (724-349-6326).

Thank you for considering participating in this study. Your help is very important to me and is greatly appreciated.

Yours sincerely,

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This project has been approved by the Indiana University of Pennsylvania Institutional Review Board for the Protection of Human Subjects (phone: 724-3557-7730)

Appendix C: Parent/Guardian & Student Signature Page

STUDENT AND PARENT/GUARDIAN CONSENT FORM: SIGNATURE PAGE

Student and Parent/Guardian need to sign

I understand the information on the form and agree to participate in this study. I understand that no one will know my individual responses to the survey. I have the right to change my mind and not participate by contacting the researcher via phone or email or by turning in a blank survey on the day the survey is administered. I have removed the bottom half of this informed Consent Form to keep for my own records.

Student's Name (PLEASE PRINT)

_____

Child's Signature

_____

Parent/Guardian Signature

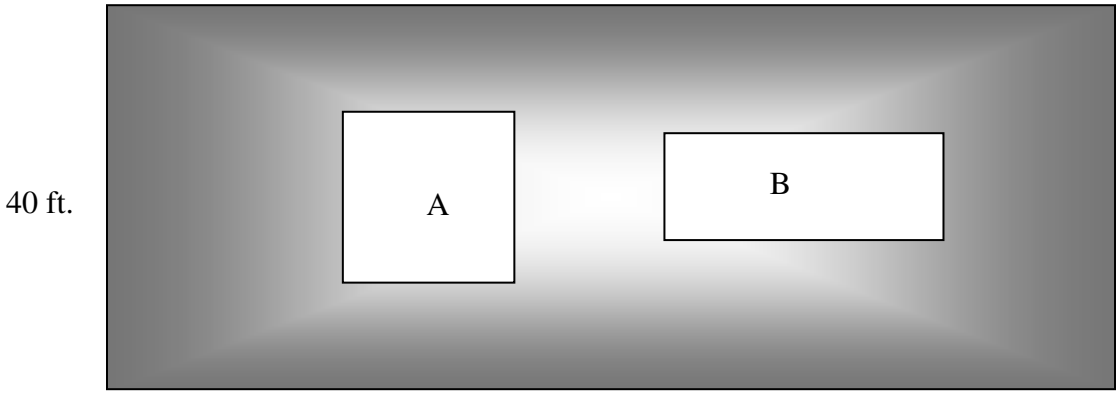
_____

Date

Appendix D: PSSA Prompt

GRADE 8 SAMPLE TASK

A rectangular courtyard is shown in the in the diagram below. The shaded portion represents grass, and rectangles A and B are cement pads for picnic tables and chairs. The area of pad A is twice the area of pad B. The remaining area is grass, which has an area of 2,040 square feet. What is the area of each cement pad?



For full credit, you must do the following:
Show OR describe each step of your work, even if you did it in your head ("mental math") or used a calculator,

AND

Write an explanation stating the mathematical reason(s) why you chose each of your steps.

Appendix E: Solving Systems of Equations

SOLVING SYSTEMS OF EQUATIONS

Write a paragraph (9-10 complete sentences) explaining each of the three ways to solve systems of equations. The three ways are: graphing, substitution, and elimination. Use your book and notes to help you. In your paragraph state which method you prefer and why. Then select one of the three problems below and solve it using your preferred method.

Bonus: Solve the other two problems using each of the other two methods.

$y = 3x + 5$
$2y - 6x = 4$

2. $9x + 4y = -17$
$12y = -3x - 3x$

3. $5x - 7y = -21$
$14y - 5y = 22$

Appendix F: Quadratic Functions

QUADRATIC FUNCTIONS

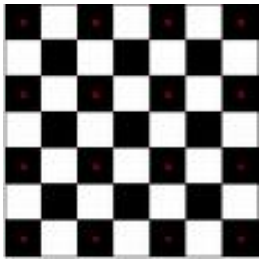
You and your friend are having trouble graphing quadratic functions of the form $y = ax^2$ and $y = ax^2 + c$. Your friend asks you to write some generalizations to help her graph these types of equations.

a. Explain the role of a.
b. Explain the maximum and minimum.
c. What is the vertex?
d. Explain the role of c.

Appendix G: Checkerboard

CHECKERBOARD

Jeff and Ali have been playing checkers and started looking at the squares on the checkerboard instead. They were trying to figure out how many squares are on a checkerboard. How many squares do you think are on a checkerboard? Show or describe each step of your work.



Appendix H: Math Poem

MATH POEM

Your math poem may be about any topic but you must incorporate at least fifteen of the following words:

Addition/Adding	Calculator	Parabola
Division/Dividing	Expressions	Perfect Squares
Mean	Percent	Power
Mode	Rational	Scientific Notation
Box-and –Whisker Plot	Inequality	Binomial
Graphs	Parallel	Combination
Integers	Slope	Triangle
Matrix	Dependent	Radius
Function	Substitution	Domain
Probability	Linear	Zero