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WRITING IN THE SECONDARY MATHEMATICS CLASSROOM:

RESEARCH AND RESOURCES

Graduate Project: A Thesis on

Adolescence Mathematics Education

by

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Master of Arts in Teaching

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______________________________
Cynthia J. Herrick
ABSTRACT

Writing in mathematics class has achieved widespread approval, if not widespread use. The National Council of Teachers of Mathematics advocates the use of writing in mathematics, and several hundred journal articles, book chapters, books, theses, dissertations, and presentations have been written about writing in mathematics. Most of these materials, however, have been subjective—some theoretical, some anecdotal, and many providing general or specific ideas about how to integrate writing into the mathematics classroom.

Within this broad area, the specific topic of interest in conducting this research was the effect of writing on the cognitive, metacognitive, and problem-solving skills of high school mathematics students. However, too little research has been done on this specific topic to allow such an exclusive focus. Thus, all quantitative research on writing in mathematics from the middle school through the college level that was subjected to tests of significance was considered. Fifty-five studies were found that satisfy this criteria.

Results were mixed. No reliable effect was found from writing on (a) overall or general mathematics achievement, (b) attitude toward mathematics, or (c) retention of mathematical information and skills. Additionally, no study found a significant negative impact from writing on achievement. Furthermore, there does seem to be an overall positive impact from writing on (a) reducing mathematics anxiety, (b) acquiring problem-solving skills, and (c) using cognitive or metacognitive processes. In addition, an argument can be made from the analysis that writing does seem to benefit female students
and low-achieving students. Finally, writing about mathematical procedures seems to have a positive impact on achievement.

Several factors make the previously outlined conclusions tentative: (a) the small number of studies meeting the research criteria, (b) the differences among types and durations of the writing interventions, (c) the differences among operational definitions of dependent variables, (d) the vastly different sample sizes, and (e) the lack of a statistical meta-analysis. Further research should be done on writing in mathematics, specifically to further elucidate the relationships between (a) writing and problem-solving, (b) writing and cognitive/metacognitive behaviors, and (c) writing that emphasizes problem-solving and cognition/metacognition and achievement in mathematics. Additionally, a statistical meta-analysis of the research to date should be completed to justify or refute the conclusions drawn in this analysis of the research literature.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>vi</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Middle School (5 – 8) Research</td>
<td>10</td>
</tr>
<tr>
<td>High School (9 – 12) Research</td>
<td>17</td>
</tr>
<tr>
<td>College Research</td>
<td>24</td>
</tr>
<tr>
<td>Results</td>
<td>41</td>
</tr>
<tr>
<td>Discussion</td>
<td>45</td>
</tr>
<tr>
<td>Summary</td>
<td>50</td>
</tr>
<tr>
<td>References</td>
<td>52</td>
</tr>
<tr>
<td>Bibliography on Writing in Mathematics, Middle School through College</td>
<td>62</td>
</tr>
<tr>
<td>Writing in Mathematics: Results Spreadsheet</td>
<td>107</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Bloom’s Taxonomy of Educational Objectives ........................................... 7
The Revised Bloom’s Taxonomy ............................................................... 8
Tally of Results from Middle School Studies ......................................... 15
Tally of Results from High School Studies .............................................. 23
Tally of Results from College Studies .................................................. 39
Tally of All Results .............................................................................. 42
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Finally, I would like to thank my husband, Dore Karasin, for his understanding, patience, interest, and support as I undertook this project.
Minus times minus is plus

The reason for this we need not discuss.

W.H. Auden (1907-1973)
INTRODUCTION

Writing to support the learning of mathematics has been a subject of interest for at least three decades, and quantitative research with results subjected to tests of significance has been conducted on the topic for over 20 years. Nevertheless, most of the published work on writing in mathematics has focused on how-to ideas, theoretical treatises, and anecdotal accounts of the success of writing in the authors’ mathematics classrooms. The quantitative research that has been conducted has yielded contradictory findings, with some studies reporting significant benefits from writing on mathematics achievement, attitude towards mathematics, mathematics anxiety, or other areas of interest, while other studies reported no significant results. Attempting to determine whether writing in mathematics is indeed an instructional method with empirical support was thus a question of importance.

This review of the research conducted to date, explored the impact of writing on a number of distinct or related areas: overall or general achievement in mathematics, attitude toward mathematics, levels of mathematics anxiety, development of problem-solving skills, development of cognitive or metacognitive skills, retention of knowledge, differential efficacy by gender, and differential efficacy by achievement level. The specific topic of interest was the effect of writing on cognitive and metacognitive skills and behaviors of high school mathematics students; it was hypothesized that writing supports students in thinking about mathematics at higher levels of the Revised Bloom’s Taxonomy, in using more metacognitive strategies, and in more successfully acquiring
problem-solving skills and knowledge than does the completion of traditional mathematics exercises. However, too little research has been done in this area to allow such an exclusive focus; all quantitative research on writing in mathematics from middle school through college with tests of significance was be reviewed. Finally, a comprehensive bibliography of all published reports, articles, and books on the subject of writing in mathematics education from the middle school level through the college level, including the materials cited in the “References” list, is provided as Appendix A. Such an exhaustive bibliography appears to be unavailable elsewhere, and so was determined to be of interest.

Rationale for the Review

Vygotsky

Russian psychologist Lev Vygotsky’s theory that learners construct knowledge through language has become a dominant theory in cognitive psychology and education. Informed by Vygotsky’s theory, the writing-across-the-curriculum or writing-to-learn movement has become mainstream; writing is seen as a standard part of best practice in the mathematics classroom as well as in other content areas.

NCTM Standards

In 2000, the National Council of Teachers of Mathematics (NCTM) published Principles and Standards for School Mathematics. Among other areas of interest, this document highlights five Process Standards, all of which may readily be related to writing in the mathematics classroom. These Process Standards are Problem Solving, Reasoning and Proof, Representation, Connections, and Communication.
The first Process Standard, Problem Solving, relates to writing in mathematics in that one of the explicitly listed goals related to problem solving is the ability to “monitor and reflect on the process of mathematical problem solving” (p. 334); this goal can readily be accomplished through the assignment of writing. Examples of the use of writing to promote monitoring and reflecting on problem-solving tasks are: assigning students the task of writing about their process of choosing among different ways to solve a problem or to analyze an incorrect answer to a problem.

The second Process Standard, Reasoning and Proof, lists the ability to “make and investigate mathematical conjectures” (p. 334) and to “develop and evaluate mathematical arguments and proofs” (p. 334) as goals. Teachers may teach these skills through direct instruction or by guiding students in exploration, and students may develop and demonstrate their acquisition of these skills through discussion. However, these goals are most readily demonstrated by writing. An example of a writing task that develops reasoning and proof skills is: using your own words, tell a younger student how to derive the formula for the area of a trapezoid from the formulas for the area of rectangles and triangles.

The third Process Standard, Representation, also relates to writing. At its heart, Representation is about converting from language labels of abstract and measurable ideas and phenomena to different types of mathematical representations: symbolic, graphical, etc. Thus, writing can support students in grasping those connections; if students write explicitly about those connections, they will be demonstrating their knowledge about representations. An example of a writing task that targets representation is: describe how the “dance” moves we learned relate to the graphs and equations of functions.
The fourth Process Standard, Connections, has as its goals the objectives that students be able to “recognize and use connections among mathematical ideas,” “understand how mathematical ideas interconnect and build on one another to produce a coherent whole,” and “recognize and apply mathematics in contexts outside of mathematics” (p. 354). Again, students can use writing to demonstrate their facility in making these connections. Examples of activities in which writing would serve to support the building of connections are: explain how statistics supports paleontologists’ acquisition of knowledge about dinosaurs, discuss the connection between geometry and Islamic art, and write a haiku about the number $\pi$.

Finally, the Communication Process Standard includes writing among the types of communication that support its goals of enhancing students abilities to “organize and consolidate their mathematical thinking through communication,” “communicate their mathematical thinking coherently and clearly to peers, teachers, and others,” “analyze and evaluate the mathematical thinking and strategies of others,” and “use the language of mathematics to express mathematical ideas precisely” (p. 348). It is clear that writing activities support the communication goals.

New York State

The New York State Education Department provides Learning Standards that make up a framework for education in New York State. Among the Mathematics, Science, and Technology Learning Standards are three that discuss the importance of communication, thus supporting the use of writing. Among the standards relating to communication in mathematics are Mathematics, Science, and Technology Standard 1:

Standard 1: Analysis, Inquiry, and Design has the following among its goals: “abstraction and symbolic representation are used to communicate mathematically,” “deductive and inductive reasoning are used to reach mathematical conclusions,” and “critical thinking skills are used in the solution of mathematical problems” (Retrieved from www.emsc.nysed.gov/ciai/pub/mststa1&2.pdf on 5/25/04). These goals echo the NCTM’s Representation, Reasoning and Proof, Communication, and Problem Solving Process Standards; examples of writing activities to support these goals were described above.

Mathematics, Science, and Technology Standard 3: Mathematics lists Mathematical Reasoning and Modeling/Multiple Representation among its Key Ideas. Mathematical Reasoning has one goal: “students use mathematical reasoning to analyze mathematical situations, make conjectures, gather evidence and construct an argument” with specific subgoals that students at commencement be able to “construct simple logical arguments” and “construct proofs based on deductive reasoning” (Retrieved from www.emsc.nysed.gov/ciai/pub/mststa3.pdf on 5/25/04). This goal again echoes NCTM’s Reasoning and Proof Standard as discussed above.

The goal of Modeling/Multiple Representation is: “students use mathematical modeling/multiple representation to provide a means of presenting, interpreting, communicating, and connecting mathematical information and relationships” with the examples that students “explain why the basic construction of bisecting a line is valid” and “describe the various conics produced when the equation $ax^2 + by^2 = c^2$ is graphed
for various values of a, b, and c” (Retrieved from www.emsc.nysed.gov/ciai/pub/mststa3.pdf on 5/25/04). This goal connects to NCTM’s Representation, Connections, and Communication Standards; the examples cited are most likely examples of writing tasks, although the goals could also be met through oral reporting.

Finally, Standard 6: Interconnectedness: Common Themes, includes many ideas and examples that require students to “describe,” “explain,” “compare,” “extend,” and “analyze” (Retrieved from www.emsc.nysed.gov/ciai/pub/mststa6&7.pdf on 5/25/04), all activities which can be facilitated by writing. This standard once again connects to NCTM’s Connections and Communications Standards.

Revised Bloom’s Taxonomy

In 2001, Anderson, Krathwohl, Airasian, Cruikshank, Mayer, Pintrich, Raths, and Wittrock published a major revision of Bloom’s Taxonomy of Educational Objectives. First published in 1956, Bloom’s Taxonomy has achieved wide acceptance in the field of education. Table 1 provides a concise overview of the original Bloom’s Taxonomy.

The revised Bloom’s Taxonomy (RBT) makes several changes over the original. The most significant change is that whereas the original Bloom’s Taxonomy was unidimensional, the RBT has separated the “Knowledge” category into (a) a memory category corresponding to the original taxonomy’s “knowledge” category and (b) a separate four-category dimension that interacts with all of the cognitive levels from the original taxonomy. Thus, the RBT is a multidimensional model. See Table 2 for a brief overview of the new taxonomy.
Table 1

Bloom’s Taxonomy of Educational Objectives

<table>
<thead>
<tr>
<th>Educational Objective</th>
<th>Skills Demonstrated</th>
<th>Question Cues</th>
</tr>
</thead>
</table>
| Knowledge             | • observation and recall of information  
                         • knowledge of dates, events, places  
                         • knowledge of major ideas  
                         • mastery of subject matter       | list, define, tell, describe, identify, show, label, collect, examine, tabulate, quote, name, who, when, where, etc. |
| Comprehension         | • understanding information  
                         • grasp meaning  
                         • translate knowledge into new context  
                         • interpret facts, compare, contrast  
                         • order, group, infer causes  
                         • predict consequences           | summarize, describe, interpret, contrast, predict, associate, distinguish, estimate, differentiate, discuss, extend |
| Application           | • use information  
                         • use methods, concepts, theories in new situations  
                         • solve problems using required skills or knowledge | apply, demonstrate, calculate, complete, illustrate, show, solve, examine, modify, relate, change, classify, experiment, discover |
| Analysis              | • seeing patterns  
                         • organization of parts  
                         • recognition of hidden meanings  
                         • identification of components | analyze, separate, order, explain, connect, classify, arrange, divide, compare, select, explain, infer |
| Synthesis             | • use old ideas to create new ones  
                         • generalize from given facts  
                         • relate knowledge from several areas  
                         • predict, draw conclusions     | combine, integrate, modify, rearrange, substitute, plan, create, design, invent, what if?, compose, formulate, prepare, generalize, rewrite |
| Evaluation            | • compare and discriminate between ideas  
                         • assess value of theories, presentations  
                         • make choices based on reasoned argument  
                         • verify value of evidence  
                         • recognize subjectivity      | assess, decide, rank, grade, test, measure, recommend, convince, select, judge, explain, discriminate, support, conclude, compare, summarize |

Note. This table quotes verbatim from the website http://www.coun.uvic.ca/learn/program/hndouts/bloom.html. The organization of the material has been slightly changed.
Table 2

The Revised Bloom’s Taxonomy

<table>
<thead>
<tr>
<th>The Knowledge Dimension</th>
<th>The Cognitive Process Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Remember</td>
</tr>
<tr>
<td>Factual</td>
<td></td>
</tr>
<tr>
<td>Conceptual</td>
<td></td>
</tr>
<tr>
<td>Procedural</td>
<td></td>
</tr>
<tr>
<td>Metacognitive</td>
<td></td>
</tr>
</tbody>
</table>

Note. This table was taken verbatim from Krathwohl (2002).

The RBT was chosen for this analysis because it addressed deficiencies in Bloom’s original design. The primary deficiency was the omission of any discussion of metacognition. Metacognition has become a major focus of interest in education in the years since the original taxonomy was published. Metacognition means investigating one’s own cognitive processes; thus, it relates to all of the areas of the original taxonomy and all of the cognitive process dimensions from the RBT.

Choice of Articles for Inclusion in the Review

In surveying the research on writing in mathematics education, only studies with quantitative results and tests of significance were considered. Literature about writing in mathematics in the primary grades was ignored, leaving 55 studies. While only secondary mathematics was of interest, research conducted at the middle school (11 studies) and college (32 studies) levels was considered because (a) there is a dearth of research at the high school level—only 12 high-school level studies were found which met the criteria.
for inclusion in this review, (b) there is overlap in teaching methods between middle school and high school and between high school and college, and (c) it was important to have as broad a basis as possible on which to form conclusions as to the efficacy of writing in mathematics. Theses and dissertations were obtained whenever possible, otherwise abstracts were consulted.

A Note about the Organization of the Review

The review is separated into sections corresponding to the middle school, high school, and college levels. Within each section, the review is organized chronologically for a variety of reasons. First, there was insufficient information about specific writing activities in many of the articles to organize the review by type of writing assigned. Second, many of the studies explored more than one outcome (i.e. achievement and anxiety), with significant results in only one of the areas. Thus, organization by successful outcome was impracticable. Third, since educational research often has a linear trajectory, it seemed that a chronological organization might point out increasingly refined experimental design, thereby allowing more specific analyses of how and why writing in mathematics classes does or does not work. The review of literature did not reveal such a pattern, but this organization was retained for the other two reasons given.
MIDDLE SCHOOL (5 – 8) RESEARCH

At the middle school level, 11 studies were found which met the criteria for inclusion in the literature review: they enumerate quantitative results subjected to tests of significance. Ten of the eleven studies had an experimental group-control group design (See Appendix B: Mathematics in Writing: Results Spreadsheet for specific details). Sample sizes ranged from 14 to 371. Study duration ranged from one unit of mathematics material to one full school year. Ten of the studies took place in different settings in the U.S., the remaining one was conducted in Lebanon. Descriptions of the individual studies are followed by analysis and conclusions.

Human (1992) explored the use of process journal writing with eighth-graders. She analyzed the journals of 14 students, starting 18 weeks after the introduction of journal writing. Using a $t$-test for one population and two- and three-way chi-square analyses of pre- and post-test scores, she found a significant effect on mathematical achievement from journal writing. She found that the process journals correlated with increased metacognitive awareness, especially for students in the low-achievement group. She found no significant difference between male and female students in achievement nor in metacognition.

Madden (1992) investigated the use of journal writing with 77 fifth-graders at a rural school district. Over the course of a semester, the teachers involved in the study required the students in the experimental treatment to write responses to prompts and to discuss their writings. Madden analyzed achievement, as measured by chapter tests and a
comprehensive exam, and retention, as measured by a retesting with the comprehensive exam after a one-month lapse. Using ANOVA and MANOVA, Madden found no significant differences between the experimental group and the control group on these measures overall.

Shepard (1992) studied the use of writing assignments with sixth-, seventh-, and eighth-grade mathematics students. The duration of the study was one instructional unit. Shepard found no impact from experimental group status on performance on a traditional mathematics examination. However, there was improvement in the use of “cognitive structures” in all experimental groups. For the experimental group, there was a significant effect on achievement using a non-traditional assessment tool that included a writing component, but this effect occurred only for the eighth-grade students.

Bauman (1992) studied the use of prompted journal writing with 182 fifth-graders at a suburban school district. Bauman gave the students a pretest; she later used the pretest scores as a covariate to analyze the data. She found no significant relationship between treatment group status and achievement in mathematics as measured by a posttest.

Burks (1993) investigated the use of writing, problem-solving strategies, and investigative processes with 371 eighth-grade mathematics students. The five teachers involved in the study provided an initial two weeks of writing-based problem-solving instruction followed by seven weeks in which two days per week focused on writing-based problem solving corresponding to the content covered on the other three days. Control group students received traditional instruction; the only problem-solving activities were those included in their textbooks. Burks found that students in the
experimental group improved in their problem-solving abilities as measured by a comparison of pretest and posttest scores and analyzed using ANCOVA. Specifically, students from all ability levels improved and low-achievement experimental group students improved to the point that their problem-solving abilities surpassed those of the high-achievement students in the control group. Students in both the experimental and the control group evidenced poorer attitudes toward problem solving after the study than before, although the opinions of the students in the experimental group declined less markedly.

DiPillo (1994) investigated the use of journal writing with 113 suburban fifth- and sixth-grade students over the course of one grading period. The experimental group students wrote in their journals to prompts given by the two teachers involved in the study roughly three times a week. DiPillo found no significant relationship between experimental group status and test results.

Albert (1996) studied the use of a “writing process strategy model” with 60 seventh-grade students. The study design used three distinct groups: one experimental and two control groups. Data consisted of pre- and post-test scores on a Student Attitude Questionnaire and a Problem Solving Test. The classroom teacher used the writing process strategy model as a framework for teaching and supporting problem solving with her students. Albert used ANOVA and ANCOVA to analyze the results. She found that experimental group status impacted significantly on problem-solving achievement.

Gilbert (1995) studied the use of problem design, writing, and Arithmetic Story Grammar (ASG) with 118 “general-ability” sixth-graders. Student writing was to specific prompts provided by the researcher; students did not receive any comments about their
writing from their teachers. The study lasted for 84 days, including 27 “treatment” days and seven days of testing. Using repeated-measures ANOVA, Gilbert found that the use of ASG worsened student attitudes and increased student anxiety when the ASG was administered alone, but no worsening of attitude and a reduction in student anxiety when the ASG was paired with writing.

Thurlow (1996) investigated the use of journal writing with 59 fifth-grade mathematics students. The study lasted for 14 weeks; data for the study consisted of pre- and post-test scores on an achievement and an attitude instrument. Thurlow used a 2x2 repeated-measures ANOVA to analyze the data. She found no significant effect from treatment group status on student achievement in mathematics nor on attitude toward mathematics.

Austin (1998) explored the use of transactional writing with racially and ethnically diverse urban middle school students over the course of a three-year grant. Thus, she was able to examine the middle school students for one, two, or three years. Students in the experimental groups wrote as a part of their homework assignments. The writing format used involved a graphic organizer. All student writings were critiqued, and revision of each assignment was required. Student achievement was evidenced by performance on the mathematics section of the Stanford Achievement Test. Attitude towards mathematics was measured by Aiken’s Revised Mathematics Attitude Scale. This paper discussed results from the first year of the study only. Data collected were analyzed by t-tests. Among students in the experimental group, female students achieved significantly higher scores in computation questions on the mathematics section of the
Stanford Achievement Test. Male students in the experimental group also showed increased performance, but not at a significant level.

Jurdak and Abu Zein (1998) explored the use of journal writing with 104 upper-middle and upper class middle-school age students at a selective private school in Beirut, Lebanon. Mathematics instruction was in French for half of the students and in English for the other half; the language of instruction was a second language for most or all of the students, whose first language was Arabic. Control and experimental sections were set up for both the English program and the French program students. The students in the experimental group responded to in-class journal prompts, three times a week for 12 weeks. The researchers used the Mathematics Evaluation Test published by the French Ministry of Education to measure conceptual, procedural, problem-solving, and mathematical communication capabilities. Items on the test were rated as pertaining to the different cognitive areas of interest prior to the beginning of the treatment. The test was given before and after the treatment period. The Attitudes Toward Mathematics Questionnaire was also administered pre- and post-intervention. Using 2x2 MANCOVA, Jurdak and Abu Zein found significant Hotelling’s $T^2$ results for the writing intervention. Subsequent univariate $F$s showed significant effects from journal writing on each of conceptual, procedural, and communication facility. No significant effects were found between writing and mathematical achievement as measured by the course examinations, nor between writing and problem-solving, nor between writing and attitudes toward mathematics.
Compiled Results

Analyzing the studies done at the middle school level, or indeed at the high school or college levels, to determine overall patterns of results is very difficult for a variety of reasons. There is a great deal of diversity in writing tasks, theoretical orientations, sample sizes, methodology, and definitions of achievement. Only two of the studies used random assignment to groups, and the procedural and methodological details of the studies are not always adequately described. Additionally, all samples were samples of convenience. Nevertheless, some results have been compiled in Table 3.

<table>
<thead>
<tr>
<th>Overall or general achievement</th>
<th>Cognitive/ metacognitive processes</th>
<th>Attitude towards mathematics</th>
<th>Reduced mathematics anxiety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Retention of information</th>
<th>Problem-solving abilities</th>
<th>Differentially more effective for female students?</th>
<th>Differentially more effective for low-achieving students?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Note. Entries in the “Yes” columns indicate significant positive effects from the writing intervention, while entries in the “No” columns indicate that the area was considered by the study and that no significant positive effects were found.
Conclusions should be drawn with extreme caution. The only clear conclusions that can be drawn from the tallies are (a) studies that explored effects on cognitive or metacognitive processes found positive effects from the writing intervention, (b) studies that explored the effects of writing on attitude toward mathematics did not show significant positive effects, and (c) there was no consistent positive effect on achievement. It should be noted that no study found a significant negative impact on achievement from writing. Furthermore, no negative effect on low-achieving students was found; the “No” responses in that column indicate only that writing was not found to be differentially more effective for low-achievers than for students of other achievement levels by those studies.
HIGH SCHOOL (9 – 12) RESEARCH

At the high school level, 12 studies were found which met the criteria for inclusion in the literature review. Nine of the twelve studies had an experimental group-control group design, and none had random assignment to groups (See Appendix B). Sample sizes ranged from 20 to 268. Study duration ranged from one unit to one full school year. Eleven of the studies took place in different settings in the U.S., the remaining one was conducted in Egypt. Descriptions of the individual studies are followed by analysis and conclusions.

Bell and Bell (1985) conducted a pilot study to explore writing with 38 students in two classes of ninth-grade general mathematics students at a public high school. During a four-week period, experimental and control group students were taught a succession of problem-solving skills, while the experimental group also completed writing assignments about the process. Using a pre- and post-test model, the researchers found that students in both groups improved in their problem-solving abilities, and that students who wrote about the process improved significantly more than did students in the control group.

Miller and England (1989) studied the use of prompted, in-class writing with Algebra I and Algebra II students at a diverse urban public high school. The students in the experimental group wrote for at least five minutes a day in class on at least 80% of school days in response to a variety of different kinds of prompts. The only quantitative result reported showed a significant positive effect from writing on attitude towards
mathematics as measured by Aiken’s Revised Mathematics Attitude Scale, but only for the Algebra II students.

Johnson (1991) explored the use of expository essays with suburban high school Algebra students. Four classes were involved in the study; one control and one experimental class taught by each of two instructors. Students were given the opportunity to consider the essay questions individually and in the large group before beginning writing. Using a one-way ANCOVA and a two-way ANOVA, he found a significant effect from experimental group status on performance on the Cooperative Mathematics Test – Algebra I from the Educational Testing Service.

Stewart (1992) and Stewart and Chance (1995) investigated the use of journal writing with four Algebra I classes over one full school year. Students wrote in class three times weekly for five minutes each time to a variety of conceptual, procedural, and class-related prompts as well as occasionally to no prompt at all (“free writing”). Stewart analyzed pre- and post-test scores on the Tennessee Comprehensive Assessment Program (TCAP) achievement examination and the Mathematics Anxiety Rating Scale for Adolescents. Using independent t-tests, Stewart found that students in the two experimental classes had significantly higher grades on the TCAP exam after the experimental treatment than did the students in the control group. She also found a difference in mathematics anxiety levels between the experimental and control groups post-treatment that was nearly significant.

Kasparek (1994, 1996) investigated the use of writing with 68 private-school Algebra II students. She used expressive and transactional writing activities integrated into the experimental groups’ classes for 12 weeks (four chapters of text). Students
completed algebra and attitude measures both before and after the treatment period. Other
data came from chapter exams and a midterm. Students in the experimental group also
wrote about a few of the questions on each examination. Kasparek used ANCOVA to
explore the data about mathematical achievement and t-tests to investigate the attitude
data. She found no overall significant difference between groups in achievement or
attitude toward mathematics. There was a trend to the data, however, that suggested a
significant difference in achievement might have been found had the study lasted longer.

Philips (1993) investigated the use of prompted content-based discussion-only
and discussion-with-writing treatments with high school Trigonometry classes. Her
results were inconsistent. Specifically, female students reported more benefit from
discussion-with-writing, which was supported by the mean of their scores on a test of
retention of mathematical information. Male students reported more benefit from
discussion alone, which was also supported by the mean of their scores on the same test.

Pugalee (1996, 2004) studied the effect of writing about problem-solving
strategies compared to using such strategies with a “think-aloud” method with 20 ninth-
grade students. Students were placed into two groups nonrandomly, but in a way to
ensure equivalence of groups. The study was preceded by a 10-day period in which
students in both groups explored problem-solving strategies in writing for 10 minutes per
day. The researcher commented on all student writing, encouraging students to be clearer,
to write more details, and to defend their strategies. For the research study, all students
were given the same “non-routine” problems, which had previously been ranked in terms
of difficulty; care was taken to ensure that students did not share problems with one
another. All students wrote half of their strategies and spoke half of their strategies as
required by the investigator. Thus, each problem was answered by one group of students working individually in writing and by the other group of students working individually aloud. Using a two-proportion $z$-test, Pugalee determined that there was no statistical difference between the groups on choice of strategy. He also used a $z$-test to discover that students made significantly less “procedural” errors when writing than when speaking, although there was no significant difference between writers and speakers in numbers of “computational” and “algebraic” mistakes. Finally, Pugalee found that students were significantly more likely to arrive at a correct answer when writing than when thinking aloud.

Brown (1996) studied the use of writing in the form of a mathematics learning log with 174 ninth- through eleventh-grade students taught by four different teachers in two different courses over one full school year. Each teacher involved in the study taught an experimental and a control class. Brown used ANCOVA to analyze the data from pre- and post-tests of writing and mathematics anxiety and from standardized tests taken towards the end of the study period. He found that the high school Algebra students who kept a learning log differed from the students in the control group in that the experimental-condition students became better at communicating mathematically and ultimately showed lower levels of anxiety about mathematics than did the students in the control group. He failed to find an effect from writing on performance on standardized tests.

Sample (1998) investigated the effect of journal writing on 78 urban ninth- and tenth-graders’ attitudes towards mathematics as measured by the Mathematics Attitude Inventory and on achievement on a test relating to integers. She used 13 writing prompts
over the course of six weeks with the students in the experimental group. Sample analyzed the attitude data using a 2x6 repeated-measures ANOVA and found no significant relationship between experimental group status and attitude towards mathematics. She also found no significant impact from experimental group status on mathematics achievement using a 2x5 repeated-measures ANOVA.

El-Rahman (1999) explored the use of writing assignments with 268 introductory Algebra students in Egypt. He used writing with two experimental groups over the course of two months for a total of 20 sessions. The first experimental group used writing individually and the second experimental group used writing as a group process. Five minutes were given for writing activities at the end of the class period, and five minutes of each following day’s class period were used for discussing the previous day’s work. There was also a control group that did not use writing. El-Rahman analyzed student achievement before and after treatment on an achievement test he had developed. The ANOVA showed a significant positive effect on achievement from experimental treatment for both experimental groups. Using a $t$-test, he found no significant difference between experimental groups, indicating that writing assignments were equally effective when completed individually and when completed in groups. He also performed a $t$-test to explore achievement as a function of gender and found no significant difference between male and female experimental group participants.

Kasten (2004) studied the use of formal writing assignments with urban ninth-graders enrolled in Algebra I or Geometry classes. She found no significant difference between experimental and control groups in either achievement in or attitude toward mathematics.
Edler (2004) explored the use of journal writing with 40 tenth-graders taking Geometry classes at a suburban high school. Students in the experimental group wrote in journals at the end of each class. He found no significant difference between experimental and control groups in mathematics test scores.

Compiled Results

A compilation of the results from the high school studies (Table 4) shows only two clear results: (a) writing increases the problem-solving abilities of the students involved in the studies that examined problem solving and (b) there is no reliable effect on achievement. It should once again be noted that no study found a significant negative impact on achievement from writing. Any other generalizations would be very hard to justify from these few and mixed results.
### Table 4

Tally of Results from High School Studies

<table>
<thead>
<tr>
<th>Overall or general achievement</th>
<th>Cognitive/ metacognitive processes</th>
<th>Attitude towards mathematics</th>
<th>Reduced mathematics anxiety</th>
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<th>Retention of information</th>
<th>Problem-solving abilities</th>
<th>Differentially more effective for female students?</th>
<th>Differentially more effective for low-achieving students?</th>
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</table>

Note. The categories for the high school studies are the same categories generated for the middle school analysis even when no high school studies addressed those categories. This was done so that results from different grade levels would be maximally comparable.
At the college level, 32 studies were found which met the criteria for inclusion in the literature review. Twenty-nine of the 32 studies had an experimental group-control group design, although only five had random assignment to groups (See Appendix B). Sample sizes ranged from 15 to 209. Study duration ranged from one assignment to two semesters. All of the studies took place in the U.S. Descriptions of the individual studies are followed by analysis and conclusions.

Pallman (1982), a college mathematics instructor, worked with an English instructor to coordinate their instruction. One of Pallman’s sections of remedial mathematics was co-enrolled with a composition class taught by the English instructor for each of two semesters. Pallman introduced a number of “languaging” exercises into this experimental section, while the college’s other sections of the course did not use these language-intensive activities. The exercises consisted of writing explanations and descriptions, giving procedures, discussing students’ affect towards mathematics, and connecting mathematics to the students’ own lives. The coordinated composition class used (at least some) mathematical content as the subject for writing. Chi-square analysis showed a significant positive impact on rates of course completion from experimental group status and a significant lowering of absenteeism in the experimental group. Achievement was measured by pre- and post-tests of a mathematics section of the California Achievement Test. There were no significant differences in achievement related to experimental group status.
Taylor (1982) studied the use of essay writing with 73 students in the second course in a two-course Business Statistics sequence. The experimental group students wrote a two-page essay describing chi-square while the control group students completed three homework problems using chi-square. The format of the chi-square examination was computational. Taylor conducted $t$-tests to explore the two groups’ exam scores. She found that the exam scores for the experimental group students were significantly higher than those for the control group students.

Hirsch and King (1983) investigated the use of writing about mathematics concepts with 83 Introductory College Algebra students randomly assigned to the experimental or control condition. Fifteen writing assignments were given as homework to the experimental group participants. Hirsch and King analyzed the data for the students in the experimental (writing) group who completed a pre-determined percentage (~66%) of the writing assignments. The researchers used $t$-tests to analyze quiz and final exam scores; they found no significant correlation between experimental group status and performance in the class. The experimental group students completed fewer traditional homework problems than did the control group, without negative impact on achievement. The authors hypothesized that poor research/instructional compatibility resulted in the lack of significant finding in favor of writing in mathematics class. Specifically, to minimize any teacher effects from the instructor knowing into which group the students had been placed, the instructor did not read, comment on, or answer questions about the writing assignments; they were read by the researchers only who were not otherwise integrated into the course.
Paik and Norris (1983, 1984) studied the use of weekly journal writing during the final two-thirds of a 15-week college course in Business Statistics. Fifty-eight students in two sections of the course participated in the study; the experimental and control groups were both made up of students who volunteered to take part in the study and who were then randomly assigned. Paik was the instructor of the class and he had students identify their journals with their social security numbers in an attempt to minimize any bias. The researchers used ANCOVA and found a significant correlation between experimental group status and grade in the course.

Selfe, Petersen, and Nahrgang (1986) investigated the use of prompted journal writing with 82 college students in three sections of a Geometry/Calculus course taught by two instructors. They gave the experimental group students 20 conceptual journal writing assignments over the period of the course. They used grades on the five course examinations as a data source; their split-plot repeated measures ANOVA showed no significant effect from experimental group on achievement. They used scores on a student attitude survey they developed as another data source; their one-way ANOVA also showed no significant effect from experimental group status on attitude towards mathematics.

Burton (1987) studied essay writing with 99 Introductory College Algebra students enrolled in five classes at the college level. Two of the classes were used as the experimental group, the other three constituted the control group. Essay writing was assigned to the experimental groups both as homework and as in-class activities over the course of a four-week period. Burton analyzed the data from pre-, post- and delayed administrations of a multiple-choice test using ANCOVA and found no significant effect
from essay writing on performance, although he did find a significant effect on retention as measured by the delayed test administration. Further, he found that students who were good at writing benefited the most from writing essays in mathematics.

Ganguli (1989) investigated the use of brief writing assignments with 50 students enrolled in two sections of an algebra review course taught by the same instructor and graduate assistant. She gave the experimental group students three minutes to respond to writing prompts at the beginning or end of every lecture class for a period of four weeks. These prompts related to definitions, algorithms, and creating word problems from abstract information. Although the students were not randomly assigned to the two course sections, a t-test on data from a pre-test designed by the college’s mathematics department showed that the groups were initially equivalent. Ganguli used a t-test on data from the course final examination and found that students in the experimental group earned significantly higher grades than those in the control group.

Lesnak (1989) investigated the use of writing with 104 Remedial Algebra college students. The students were randomly assigned by the registrar to one of four sections of the same course taught by Lesnak; two sections served as the experimental group and two served as the control group. The experimental group students wrote general procedures for solving different kinds of problems and were encouraged to refer to their writings throughout the semester. These students also wrote about the procedures to review for the course examinations. Lesnak found a significant effect on course grade from experimental group status.

Youngberg (1990) explored the use of writing assignments with four sections of a two-semester college Introductory Algebra sequence at a small private college. All
sections were taught by Youngberg with random assignment of students each semester to either one of the writing sections or one of the control sections. Data for the study came from a pretest and a posttest produced by the textbook publisher, three content exams written by the investigator, and an attitude scale developed by the investigator. She used four 2x2x2 ANOVAs and found that experimental group status had a positive effect on performance on the course midterms and final examination. Specifically, she discovered improved performance overall but especially on test items related to writing assignment topics. Furthermore, she found that students entering the course with below-median scores on a pretest as well as students entering the course with above-median pretest scores benefited from writing, although above-median students showed slightly greater improvement.

Beins (1991, 1993) studied the use of writing “press releases” (brief, “jargon-free” summaries of statistical results) on the performance of 122 college Statistics students; all students were Psychology majors. One section of the course received “high-emphasis” in writing and interpretation; this section wrote the press releases. Two sections received “moderate-emphasis” and wrote only briefly but also spent class time practicing statistical interpretation skills. The final section of the class was considered “traditional-emphasis” and also wrote only briefly. Beins used the course final examination as his data source; the exam had three components: computation, interpretation, and conceptual knowledge. He used MANOVA to analyze the data and found that students in the high-emphasis writing group evidenced significantly higher computational and interpretation scores than students in the other groups. He found no significant difference in conceptual knowledge among the groups.
Austin (1992) studied the use of transactional writing with 87 college students taking Introductory Algebra. Pre- and post-tests of the Elementary Algebra Test and the Revised Mathematics Attitude Scale were used to generate data. She used a t-test on the pre-test data to determine that the experimental and control groups were not initially equivalent and so used ANCOVA to analyze the post-test data. She found no significant effect on achievement or attitude from experimental group status.

Guckin (1992) studied the use of “informal focused” writing in college Introductory and Intermediate Algebra classes. She found a significant effect from experimental group status on student grades on two of the three course examinations under consideration.

Sabrio, Sabrio, and Tintera (1993) explored the use of prompted writing assignments in Remedial Algebra and Introductory Algebra at a rural, largely Mexican-American university. The two instructors involved in the study each taught one control and one experimental section; the same instructor taught both remedial classes and the same instructor taught both introductory classes. The 131 students involved in the study were not randomly assigned to the treatment and control groups, but the experimental classes’ mean ACT and SAT scores were determined to be equivalent to those of the control classes. Writing assignments focused on course content and on feelings toward mathematics and the course and were completed by the students in the experimental group once weekly. The researchers found no significant effect from experimental group status on rates of passing the course.

White (1993) explored the use of writing and rewriting with college developmental mathematics students. The students each completed three writing
assignments and revisions on those assignments. White found no significant difference in scores on course examinations between the experimental and control groups.

Baker (1995) investigated the use of in-class writing to prompts requiring explanations with 209 College Algebra students. Students in the two experimental sections of the course wrote explanations of the course content twice weekly during the eight week duration of the study, while students in the control group discussed examples. The instructor gave daily feedback to the students in the experimental group on their writings. Baker found that, although there was no overall significant effect on achievement or attitude from the experimental condition, there were some specific significant results. First, those experimental group students whose previous performance in mathematics was poor experienced significantly better attitudes toward mathematics than did the similar control group students. Second, those experimental group students who had not taken a mathematics course in the previous 1 ½ years experienced significantly higher mathematics achievement than did similar students in the control group.

Isom (1996) explored the use of brief, graded writing exercises with 42 students in two sections of Business Calculus; one section served as the experimental group while the other acted as the control group. He used a derivative pre-test that he developed as the data source to determine whether the groups were initially equivalent; they were. He used Hotelling’s $T^2$ to analyze the achievement data from the researcher-developed midterm examinations, a post-test administration of the derivative tool, and a problem-solving assignment. He found a significant effect on achievement from experimental group
status. He used a paired $t$-test to determine that there was no significant effect from treatment on a student beliefs survey administered pre- and post-test.

Davis (1996) studied the effect of writing on 40 college students taking an Introductory Statistics class. Students in the experimental group completed seven writing-based homework assignments over the course of the semester. Both control and experimental groups were taught in a traditional, lecture format. Davis used $t$-tests to uncover a significant effect from experimental group status on class grade. He also used regression to determine that experimental group status had a significant positive effect on the grades of both high- and low-achievement students.

Porter (1996) and Porter and Masingila (2000) investigated the use of writing with 33 students in two sections of a concept-based course in Introductory College Calculus; one section served as the experimental group while the other section served as the control group. Both sections were taught by the same instructor and completed similar conceptual and procedural activities followed by discussion; however, only the experimental group wrote their answers to the activities. Students in the experimental group wrote about the course content both in- and out-of-class on slightly less than half of the course’s instructional days. The researchers used a $t$-test to analyze students’ scores on the Mathematical Association of America’s Calculus Readiness Test to determine whether the two groups were initially equivalent; they were. The researchers coded and analyzed the types of errors made by students on the three course examinations and on the final examination. They used ANOVA to discover that there was no overall significant difference between the experimental and control groups on number or type of calculus-level errors made and did not analyze algebra or pre-calculus level errors. They
used MANOVA to determine that there was no difference between the groups on either overall or particular types of conceptual or procedural mistakes.

Heath (1997) investigated the use of writing with 48 students in two sections of College Pre-Calculus; one section served as the experimental group while the other served as the control group. Heath developed a form for students to fill out on a daily basis that gave students a structure for their class notes and an avenue for examining their own understanding. Data for the study came from a pre- and post-test of course content and from a student attitude assessment. She found a positive impact on achievement as measured by the post-test from experimental group status.

Abbey (1997) investigated the use of “guided response journal writing” with 12 sections of Introductory Algebra students at a two-year college over the course of a semester. Three different instructors taught the sections. The experimental design involved four different groups: students completing the guided response journal entries, those completing guided “non-response” journal entries, those completing graded homework assignments, and those completing homework that was not graded. Data for the study came from an achievement pre-test, the course final examination, and pre-and post-test administrations of a mathematical attitude tool. Abbey found no isolable effect from group status on achievement, but did find a significant effect from all experimental group statuses on students’ attitude towards their mathematics instructors.

Williams (1997, 2003) investigated the use of writing with 42 Introductory Algebra students at a community college over the course of one semester. Students were taught problem-solving techniques and were given challenging, non-routine problems to solve in addition to more typical algorithmic assignments. Students in the experimental
group were additionally required to write one- to two-paragraph reflections about their problem-solving processes with each of the non-routine problems. Data for the study came from pre- and post-tests and homework grades on the final thirty non-routine problems. Pre-test data was analyzed with a $t$-test; the experimental and control groups were determined to be initially equivalent. Further $t$-tests showed that, although students in both groups improved in their problem-solving abilities as shown by comparisons of the pre- and post-test data, students in the experimental group improved significantly more than did those in the control group. He also found that students in the experimental group scored significantly higher on the non-routine problems themselves than did the control group students.

Sydney (1997) studied the use of out-of-class assigned journal writing with 21 Introductory College Algebra students. The data for the study came from pre- and post-tests of attitude and achievement. Sydney found no significant effect on attitude from experimental group status, but she did find a positive effect on achievement. Furthermore, she found no significant differential effects on achievement or attitude to be correlated with participant gender or first language.

Rodgers (1997) studied the use of writing with 120 students taking either College Algebra or a mathematics class for prospective elementary school teachers. All students were taught with a “traditional” method, but half of the students completed a writing component in addition to traditional assignments. Data for the study came from pre- and post-tests of attitude and achievement. Rodgers found no significant effect from treatment group status on either achievement or attitude for students in either course.
Giovinazzo (1997) investigated the use of conceptual writing with 47 College Algebra students. Her experimental and control groups were initially equivalent in mathematics achievement as measured by the College Algebra Test, but were initially different in levels of mathematics anxiety as measured by the Phobos Inventory; a \( t \)-test indicated that the experimental group showed significantly higher levels of anxiety toward mathematics. Giovinazzo used ANCOVA and \( t \)-tests to find no significant differences in either achievement or anxiety post-treatment using the same tools, indicating that writing ameliorated student anxiety. She did find that students in the experimental group had higher final averages in the class.

Bolte (1997) investigated the use of a combination of concept-mapping and coordinated essay-writing with 103 students taking one of three college mathematics classes – Calculus I, a content class for prospective elementary teachers, or a different content class for prospective secondary mathematics teachers. She found that grades on the concept maps/essays were more highly correlated with final grade than were homework and quiz grades, especially for the Calculus I classes. She did not indicate how each of these components was weighted in the grading process, however, so it is difficult to interpret these results.

Austin (1998) explored the use of transactional writing with Introductory and Intermediate Algebra students at the community college level over the course of a three-year grant. Students in the experimental groups wrote as a part of their homework assignments. All student writings were critiqued, and revision of each assignment was required. Student achievement was measured pre- and post-treatment by different versions of the Elementary Algebra Skills Test from the Florida Multiple Assessment
Programs and Services: Assessment and Placement Services Colleges and Universities Program, whereas attitude towards mathematics was measured by pre- and post-test administrations of Aiken’s Revised Mathematics Attitude Scale. This paper discussed results from the first year of the study only. Austin used $t$-tests to determine the initial equivalence of the experimental and control groups. She then used $t$-tests to examine the post-test data. She found that for “returning students,” writing showed a significant positive effect. Among remedial students, the writing treatment correlated significantly with percentage of students passing the course. No significant effect on rate of course completion was found. Factor analysis showed no significant overall effect on attitude towards mathematics.

Abu Diab (1998) explored the use of writing assignments with 120 students taking Finite Mathematics and Basic Statistics college classes. Thirty-two of the students were non-native English speakers, while the other 88 students did speak English as a first language. The students in the experimental group completed writing assignments about concepts, analysis, and problem-solving. Data for the study came from pretests, two course examinations, the final examinations, and an attitude instrument. Analyses of the data showed no significant effect on achievement or attitude for the language-minority students from experimental group status.

Atkins (1998) studied the use of structured in-class writing with 34 Calculus I students at a rural community college. The experimental and control class curricula were both informed by a multiple-representation, problem-solving focus. The experimental group completed structured writing tasks at least twice a week; the control group completed problem-solving exercises without a writing component. Data for the study
came from pre- and post-tests of the Multiple Representations Test and a mathematics attitude scale as well as from post-treatment administrations of the Calculus Applications Test and the Student Perception Survey. He found that students in the experimental group showed better understanding but slightly lower achievement than the control group students. He also found that writing students’ attitudes toward mathematics improved more than did the control group students’ attitudes.

Goss (1998) studied the use of in-class writing assignments with students enrolled in two sections of Calculus I taught by the same instructor at a small liberal arts college. One section served as the experimental group while the other section formed the control group. Students in the experimental group completed two 10-minute writing assignments per week during class for the duration of the semester. The assignments focused on course concepts. The course instructor was not the researcher; the researcher commented on each writing assignment, but the assignments were not graded. The control section of the class used the same period of time for discussion about the same concepts. Goss used two-way ANCOVA to determine that there was no significant effect on achievement as measured by course means from experimental group status (The covariates were ACT scores). She also found no differences between males and females overall nor as an interaction with treatment from the two-way ANCOVA and also used a $t$-test to determine that there was no significant difference between the means of the male and female students in the experimental group.

Sgoutas-Emch and Johnson (1998) investigated the use of journal writing in College Statistics classes. Two sections of the same course taught by the same instructor participated in the study; one section was randomly chosen to be the experimental group
while the other class formed the control group. Journal entries consisted of thoughts and feelings about the class as well as a summary of each day’s lecture; ample time to begin each entry was given at the end of each class period. The researchers collected and gave feedback on the journals three times during the semester. Initial data came from scores on the Basic Math Test, the Spielberger Trait Anxiety Scale, the Test Anxiety Inventory, and the Achievement Anxiety Test. Additionally, pre- and post-test administrations of the Statistics Anxiety Inventory and the Statistics Attitude Scale were completed. Furthermore, on each exam date, administrations of the Spielberger State Anxiety Questionnaire – Short Version were given before and after the exams, the Perceived Performance and Difficulty Scales were completed after the exams, and the Journal Efficacy Scales were also completed. Finally, at the beginning of the course and before and after each examination, saliva samples were collected for cortisol analysis (cortisol levels are known to correlate with anxiety). Analysis of initial data by independent $t$-tests showed no significant difference between the experimental and control groups’ scores on any of the anxiety instruments, including the cortisol analysis, nor on the Basic Math Test, nor on the Statistics Attitude Inventory. Two-way ANOVA showed that there was no overall significant effect from journal writing on anxiety or attitude. However, the researchers did find a non-significant decrease in anxiety from the beginning of the semester to the end in the experimental group and an increase in anxiety over that period in the control group. They also found that the control group was significantly more anxious prior to the exams than was the experimental group, with no significant difference between groups in anxiety measured after the exams. For three out of four of the exams, the experimental group members’ level of salivary cortisol decreased more
during the course of the exams than did the control group members’. Furthermore, there was no overall significant result on test performance from experimental group status, although the mean score for the students in the experimental group increased over the period of the experiment while the mean score for the students in the control group remained constant. Finally, the researchers did not find a significant improvement in attitude toward statistics in either the control or the experimental group.

Loud (1999) examined the use of structured journal writing with students in a college mathematics course focused on concrete applications. Students in the experimental sections of the course completed journal entries in which they described steps in completing problems, summarized course content, and discussed concepts. Data for the study came from scores from a Beliefs Survey and grades on the course final examination. Loud found a significant effect from experimental group status on final exam scores and on beliefs toward mathematics. Additionally, stepwise regression showed that, among the students in the experimental group, there was a significant correlation between improved performance in explaining and describing processes and final exam score.

DiBartolo (2000) studied the use of writing with 15 students in a college mathematics survey course at a large urban university. She considered the course term paper to be “formal” writing and writing as part of course examinations to be “informal.” She developed two different rubrics to score these two different types of writing. She measured attitude towards mathematics pre- and post-test using a survey she developed, a tool that was partially informed by the Fennema-Sherman Usefulness of Mathematics Attitude Scale. She found a strong correlation between improvement in writing and
improvement in mathematics performance on course exams for those students in the middle level of achievement in the course. She also found an improvement in attitude towards mathematics among students in both the upper and lower levels of mathematics achievement to be correlated with the use of writing.

Compiled Results

A compilation of the results from the college studies (Table 5) was especially difficult to create, since some of the studies explored, for example, different areas of achievement and found significant results in one area and no significant results in another. In this situation, any summary may show some subjectivity. Nevertheless, results were compiled.

Table 5

Tally of Results from College Studies

<table>
<thead>
<tr>
<th>Overall or general achievement</th>
<th>Cognitive/metacognitive processes</th>
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Note. The college review also showed one study with a significant effect on the rate of student completion of the course and on student absenteeism, while another study showed no significant effect on course completion rate.
Again, only a few conclusions can be drawn with any degree of reliability. First, writing did not have a reliable significant effect on either achievement in or attitude towards mathematics. Second, writing was not differentially more effective for female students than for male students. Third, writing does seem to have a positive effect on students’ cognitive and/or metacognitive functioning.
RESULTS

The results from all of the studies may be tallied. However, doing so magnifies the problems associated with tallying the results because not only are different kinds of studies with different numbers of participants exploring different kinds of writing and looking at results operationalized in different ways, but such an overall tally also introduces two other complicating factors: (a) the students are of different developmental levels whose corresponding learning processes are known to be distinct, and (b) the types of mathematics being learned varies from arithmetic operations in middle school through Calculus and Statistics in college. The cognitive demands of these different types of mathematics are also quite distinct. Despite these serious reservations, Table 6 shows a tally of all of the results despite these serious reservations so that an overview of the body of research may be seen.

A few observations may be made, albeit with serious reservations. First, there does not seem to be a reliable impact on (a) overall or general mathematics achievement, (b) attitude toward mathematics, (c) retention of mathematical information and skills, (d) a differential benefit for female students, or (e) a differential benefit for low-achieving students from writing interventions. Second, there does seem to be an overall impact on (a) mathematics anxiety, (b) the acquisition of problem-solving skills, and (c) the use of cognitive or metacognitive processes from writing interventions. However, the small number of studies discussed and the lack of a statistical meta-analysis make any conclusions difficult to justify.
Furthermore, no study showed a significant negative impact on achievement—the “No” categorization simply means lack of significant positive result. Similarly, no study showed a negative impact on low-achieving students or female students, the “No” categorization means that writing failed to produce significantly differentially more positive results with students from those groups. Analysis of the “No” entries in row 32 (effect on female students) with the entries in row 28 (effect on achievement) of the Writing in Mathematics: Results Spreadsheet in Appendix B shows that there was a significant impact on achievement for students of both genders for two of the six studies that reported no differential positive effect for females. Additionally, there were two other studies that showed mixed achievement results for students of both genders. Thus, while writing cannot be claimed to be reliably more effective for female students than for
male students, it does impact on achievement in over half of the studies (two studies that showed differential results plus four that showed a non-differential effect versus four that showed no effect on achievement).

Similarly, analysis of the “No” entries in row 33 (effect on low-achievers) with the entries in row 28 (effect on achievement) shows that there was a significant impact on achievement of students of all achievement levels for one of the four studies that showed no differential positive effect for low-achieving students. Additionally, there were two other studies that showed mixed achievement results for students of all achievement levels. Thus, I believe that a claim can be made, albeit with some reservations, that writing is effective for low-achieving students because it was effective for them in two-thirds of the studies (three studies in which it was differentially more effective plus three were it was non-differentially effective versus three that showed no effect on achievement).

Additional analysis shows that for the eleven studies that stated an emphasis on writing about mathematical procedures, seven showed an effect on achievement, two showed no effect on achievement, and two did not investigate achievement. Thus, there is tentative support for the idea that writing about procedures impacts positively on student achievement in mathematics.

Analysis of relationships between all other assignment descriptions (integral to class, graded and/or commented on, revision, concepts, problem-solving, cognitive/metacognitive, with discussion) and overall achievement shows very mixed results. Thus, while there may be a relationship between some or all of these assignment
variables and achievement, a statistical meta-analysis and/or further research is necessary
to uncover such a relationship.
DISCUSSION

To answer any general questions about the use of writing in mathematics, including questions about the overall efficacy of writing to improve achievement in or attitude towards mathematics, a statistical meta-analysis of the research cited in this review should be completed. From the tallies, it appears that there is no overall support for believing that writing intervention improves achievement or attitude, but a more careful analysis of the content of the studies cited is necessary before any such conclusions can be more definitively drawn. Furthermore, definitions of achievement need to be carefully operationalized. Specifically, one wonders whether the apparent overall lack of impact on achievement may be somewhat due to how achievement in mathematics is defined. If achievement is defined by scores on a multiple-choice standardized examination, for example, we may be neglecting more salient types of achievement (problem-solving ability, the ability to make connections among different areas of mathematics or between mathematics and other subject areas, the ability to switch between different representations of problems with facility, etc.) that may matter more in helping students become mathematically involved and adept.

There is insufficient evidence at this point to determine whether there is a reliable benefit to be had from writing in the mathematics class. The specific areas of interest—the use of cognitive or metacognitive processes and the acquisition of problem-solving skills—receive some support from the research review. That is, writing does seem to impact positively on these areas. Both of these areas of interest can be conceptualized as
reflecting different cells from the Revised Bloom’s Taxonomy (RBT). Specifically, different cognitive processes form one dimension of the taxonomy, metacognition is one element of the knowledge dimension and thus interacts with all of the cognitive processes, and problem-solving can be thought of as incorporating the cells formed by the intersections of the “apply” and “analyze” categories of the cognitive dimension with the “procedural” and “metacognitive” categories of the knowledge dimension. Thus, the research questions can be collapsed into one question: Does writing to learn support the development of thinking at more complex levels of the RBT? While there does seem to be some confirmation for the hypothesized benefit from writing on thinking from the present review of the literature, more research must be done.

The Next Step

The next step in answering this question should be the completion of a quasi-experimental study with high school mathematics students over the course of at least one full quarter. First, curriculum and assessments need to be developed with the use of the RBT table in order to ensure that students are being challenged to think about and process mathematics at more sophisticated levels. Computational fluency and algorithmic recall should remain as goals of this new design, but they should not be the only focus of the curriculum and assessment as they are so much in mathematics education. Second, the curriculum and assessment thus developed should be adapted to show a writing-intensive focus. The types of writing involved in the adapted design should be a mix of prompted journal writing, more formal writing assignments with required revisions, writing exercises on quizzes and exams, and writing in small groups, and the assignments obviously need to have a predominantly problem-solving, cognitive, and/or
metacognitive focus that reflects the importance of those areas in the initial course
design. The teacher should respond to all writings promptly and regularly, and the non-
journal writing assignments should all be graded.

The quasi-experimental design should include three different groups: one control
group taught the same mathematical topics in a more traditional, computationally-focused
manner and two experimental groups—one taught using the non-writing-intensive RBT-
group informed curriculum and assessments and the other taught using the writing-intensive
RBT-informed curriculum and assessments. It may seem that there should be a fourth
group for comparison—a group taught a traditional curriculum with a writing focus.
However, it appears that much traditional mathematics education is focused on
developing only certain areas of thinking from the RBT, specifically the intersections of
the “remember” and “apply” cognitive processes with the “factual” and “procedural”
knowledge processes. However, any writing assignments will necessarily involve at least
the “conceptual” knowledge process and the “understand” cognitive process, and could
also involve the other processes. Thus, it seems impracticable to attempt to develop
writing assignments that do not reflect these other areas of thinking.

Data for the study should come from a variety of sources. First, scores on state
mathematics examinations should be considered for three reasons: (a) scores from prior
years can be used as one measure in determining whether experimental and control
groups are initially equivalent, (b) it is necessary to assure that any development of more
complex mathematical processing is not at the cost of lowered computational and
algorithmic recall and ability, and (c) the federal No Child Left Behind legislation and
New York State requirements for graduation emphasize the use of these standardized
tests; since testing is such a critical part of the current educational setting, ignoring testing seems irresponsible in any evaluation of mathematics achievement.

Second, a reliable, validated mathematics attitude assessment like the Attitudes Toward Mathematics Inventory (see Tapia and Marsh, 2004) should be given pre- and post-test to all participants. Although it does appear from the literature that writing does not have a significant positive effect on attitude toward mathematics, it is very difficult to altogether reject the idea of such an impact. Mathematics educators tend to love mathematics and to think that if students were only able to engage with the material on deeper and/or more personal levels, they would develop an appreciation for the power and beauty of mathematics as well. Writing assignments can be designed to require such engagement; thus, effect of writing on attitude should be a continuing focus of research.

Third, a content-specific, problem-solving instrument needs to be developed. Problems for the instrument should be non-routine and require a variety of different problem-solving strategies. Problems can be taken from sources like the Math Forum’s Problem of the Week website (http://mathforum.org/pow/) and the Education Development Center’s Problems with a Point website (http://www2.edc.org/mathproblems/help.asp) which was funded by a National Science Foundation grant. Strategies used and responses given should be analyzed by a coding protocol that examines different types of problem-solving strategies, frequency of problem-solving behaviors, and success at problem-solving.

Fourth, an instrument needs to be developed that would allow the researcher to explore the cognitive and metacognitive processes of the participants. This tool needs to have a variety of exercises corresponding to the different cells in the RBT table. Since it
is not a given that students will process problem situations as predicted (see Gierl, 1997) a coding protocol also needs to be developed to determine into which cell(s) of the RBT students’ thinking processes and responses fall.

Commentary

Conclusions drawn from this review of the literature are necessarily few and of questionable validity, for reasons previously stated. Nevertheless, this review constitutes an important addition to the literature on writing in the mathematics classroom. This review of all of the quantitative research studies on the topic provides a first step towards an empirical answer to the question of whether writing is effective in supporting the learning of mathematics. The research study proposed above would constitute another step in this process and would explore cognitive and metacognitive processes more explicitly than did previous studies. Furthermore, Appendix A is the only current, comprehensive bibliography available on writing in mathematics.
SUMMARY

Writing in mathematics class has achieved widespread approval, if not widespread use. The National Council of Teachers of Mathematics advocates the use of writing in mathematics, and several hundred journal articles, book chapters, books, theses, dissertations, and presentations have been written about writing in mathematics. Most of these materials, however, have been subjective—some theoretical, some anecdotal, and many providing general or specific ideas about how to integrate writing into the mathematics classroom.

Within this broad area, the specific topic of interest in conducting this research was the effect of writing on the cognitive, metacognitive, and problem-solving skills of high school mathematics students. However, too little research has been done on this specific topic to allow such an exclusive focus. Thus, all quantitative research on writing in mathematics from the middle school through the college level that was subjected to tests of significance was considered. Fifty-five studies were found that satisfy this criteria.

Results were mixed. No reliable effect was found from writing on (a) overall or general mathematics achievement, (b) attitude toward mathematics, or (c) retention of mathematical information and skills. Additionally, no study found a significant negative impact from writing on achievement. Furthermore, there does seem to be an overall positive impact from writing on (a) reducing mathematics anxiety, (b) acquiring problem-solving skills, and (c) using cognitive or metacognitive processes. In addition, an
argument can be made from the analysis that writing does seem to benefit female students and low-achieving students. Finally, writing about mathematical procedures seems to have a positive impact on achievement.

Several factors make the previously outlined conclusions tentative: (a) the small number of studies meeting the research criteria, (b) the differences among types and durations of the writing interventions, (c) the differences among operational definitions of dependent variables, (d) the vastly different sample sizes, and (e) the lack of a statistical meta-analysis. Further research should be done on writing in mathematics, specifically to further elucidate the relationships between (a) writing and problem-solving, (b) writing and cognitive/metacognitive behaviors, and (c) writing that emphasizes problem-solving and cognition/metacognition and achievement in mathematics. Additionally, a statistical meta-analysis of the research to date should be completed to justify or refute the conclusions drawn in this analysis of the research literature.
REFERENCES


APPENDIX A

Bibliography on Writing in Mathematics, Middle School through College


Goldsby, D. S. (2002). Writing samples to understand mathematical thinking. *Mathematics Teaching in the Middle School, 7*(9), 517-520.


Poluse, M. T. S. (2002). The effects of expressive writing on high school pre-calculus students’ understanding, formal communication skills, and attitudes toward writing and mathematics (Doctoral dissertation, Kent State University, 2002). *Dissertation Abstracts International, 63*(6), 2117A.


Rishel, T. W. (1990). Writing in the math classroom; math in the writing class (or how I spent my summer vacation). In A. Sterrett (Ed.), *Using writing to teach mathematics* (pp. 30-33). Washington, DC: Mathematical Association of America.


APPENDIX B

Writing in Mathematic: Results Spreadsheet

Legend for the spreadsheet:

α. AB means abstract and/or dissertation/thesis, C means book chapter, E means EDRS, J means journal article, O means other, W means internet

β. Y means yes, N means no, C means individuals were not randomly assigned, but classes were randomly assigned to treatment groups which were found to be initially equivalent

χ. A I means algebra I, A II means algebra II, C means calculus, G means geometry, M means general middle school, O means other, P means precalculus, S means statistics, T means trigonometry

δ. a means assignment, d means day, m means month, Q means quarter, s means semester, u means unit, w means week, y means year, blank means unknown

ε. H means non-journal homework, I means non-journal in-class assignment, J means journal

θ. blank means U.S.

γ. C means community/two-year college, D means unknown, P means private, S means state

η. For these rows, Y means yes, N means no, blank means unknown

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θ. D means differential positive effect, Y means positive effect discussed, but not differentially more positive for those groups, N means the study examined this and found no positive or differential positive effect, blank means that this outcome was not a focus of this study
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**Prompt types:**

- **Expository writing**
- **Essay writing**

**Students**

- were co-enrolled in a cooperating section of freshman composition.
- There was a significant positive impact on rate of course completion and a significant lowering of absenteeism for students in the experimental group.
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<td>* Graded and commented on by researcher, not instructor</td>
<td>Essay writing</td>
<td>* Study lasted 2 semesters, but each student was involved for only 1 semester</td>
<td>Essay writing</td>
<td>* Study lasted 4 semesters, but each student was involved for only 1 semester. Also, study participants chose to be in the study by volunteering for extra credit</td>
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<td>Procedural and conceptual errors were analyzed.</td>
<td>Concept maps and interpretive essays were used.</td>
<td>Students volunteered for extra credit.</td>
<td>Writing was formal and in a term paper.</td>
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