

DISSERTATION

EFFECTS OF WRITING TO LEARN IN PRE-CALCULUS MATHEMATICS ON
ACHIEVEMENT AND AFFECTIVE OUTCOMES FOR STUDENTS IN A COMMUNITY
COLLEGE SETTING: A MIXED METHODS APPROACH

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ABSTRACT

EFFECTS OF WRITING TO LEARN IN PRE-CALCULUS MATHEMATICS ON ACHIEVEMENT AND AFFECTIVE OUTCOMES FOR STUDENTS IN A COMMUNITY COLLEGE SETTING: A MIXED METHODS APPROACH

The intent of this study was to explore an intervention, *Writing to Learn*, within a college level mathematics course and examine how *Writing to Learn Mathematics* as an assessment tool in Trigonometry relates to overall achievement and self-reflection with respect to learning mathematics. The purpose of this study was to provide empirical evidence and determine the effect such an intervention had on undergraduate students' academic achievement as well as their mathematic conceptual growth and metacognitive growth.

This study employed a mixed method approach using a qualitative study design element with emphasis on template analysis and was supported with inferential statistics from a cross-over study design implemented in a concurrent and parallel format. The quantitative portion of the study examined differences in students' exam scores for the portion of the course where students experienced *Writing to Learn Mathematics* versus the portion of the course where students did not experienced *Writing to Learn Mathematics* to determine if writing had an effect on students' performance on exams. While the results from the quantitative portion of the study were not statistically

significant, effect sizes indicated a small effect. Paralleling the quantitative phase, the qualitative portion of the study utilized an approach referred to as Template Analysis to reveal the nature of students' individual metacognitive functioning and changes that occurred during the course of this study as students utilized various writing activities which engaged students in individual reflective writing as part of the course. The initial, *a priori*, codes were modified, expanded, and revised to reveal three themes focused on metacognitive transformations: changes as a learner, reflections and writing, and value of writing.

While there were inconsistencies between results due to different methodological approaches in data collection, information that may otherwise have been overlooked was available. The integration of results revealed many students made significant changes in approaches to learning and also made deep and meaningful conceptual connections as a result of *Writing to Learn Mathematics*. It also was apparent writing in mathematics and about mathematics encouraged students to reflect on what they were learning and facilitated meaningful connections about content and themselves as learners.

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CHAPTER 1: INTRODUCTION

There is a gap in the literature with respect to alternative assessment in higher education. A review of the literature indicates there is definitely a need for more and substantial research in higher education implementing alternative assessments and analyzing the effects on learning (Angelo, 1999; Ewell, 1991, 2008; Hlebowitsh, 1995; Sternberg, 2008; Stiggins, 2004; U.S. Department of Education, 2006). This need is prevalent in higher education across all disciplines and most especially in mathematics. This type of intervention research will add to the field of study by examining effects directly related to the gap indicated in the literature for alternative assessment in higher education. A review of the literature indicates there is most definitely a call for more and substantial research in higher education implementing alternative assessments and analyzing the effects on learning. The alternative assessment strategy analyzed in this research project has been demonstrated in various types of professional development activities to both local and national audiences by this researcher/educator. Statistical evidence could provide additional empirical support for implementation and continuation of such an assessment tool in other arenas in higher education.

The findings of this study can also contribute to the knowledge base of metacognitive processes and metacognitive changes students' exhibit during their writing about mathematical processes and self evaluative exercises. While there is some existing research connecting problem solving processes in mathematics and metacognition (Artzt & Armour-Thomas, 1992; Desoete, Roeyers, & Buysse, 2001; Fusco,

1995; Goos, 1994; Goos, Galbraith, & Renshaw, 2002; Mevarech, 1999; Oladunni, 1998; Pugalee, 2001), there is limited research focusing on metacognitive process and metacognitive changes that emerge as college-level students write and reflect on their mathematical endeavors through alternative assessments. Patterns of metacognitive behaviors exhibited throughout the writing process and how these behaviors affect overall course performance will be identified. As the majority of studies on metacognitive behavior and mathematics performance emphasize problem solving, this study shifted the emphasis to mathematical communication which also is a central focus of both mathematics curriculum and instruction (NCTM, 2000). It requires research-based suggestions for helping students develop monitoring and regulating behaviors for their mathematical communication in addition to their problem solving activities. This is particularly essential for current community college, college, and university teachers who are responsible for making their mathematics teaching learning centered and for developing and enhancing their students' metacognitive abilities. There is a need for additional research based on limited empirical findings focusing on metacognitive processes that emerge as college-level students write and reflect on their mathematical endeavors through alternative assessments.

Background

The early 1980's saw an emergence of assessment as a central reform issue in higher education. This reform was clearly delineated in four major reports on undergraduate education. These reports were all stimulated by prior inquiries into national deficiencies in elementary and secondary education from the 1983 publication *A Nation at Risk: The Imperative for Educational Reform* completed by the National

Commission on Excellence in Education, a group convened by then Secretary of Education Terrell M. Bell. One of the major issues brought forth by the Excellence Commission that is of interest to many educators today is student academic achievement (National Commission on Excellence in Education, 1983).

As student achievement and student assessment are directly connected each of the four reports related to assessment in higher education, expanded on in detail in the next chapter, had its own connection to assessment and undergraduate reform. As summarized by Ewell (1991), *Access to Quality Undergraduate Education* provided support for the need to identify and address growing basic skills deficiencies among incoming college freshmen. This report signaled the rebirth of basic skill testing across the nation in higher education. The second report *Involvement in Learning* per Ewell (1991) stated the link between high standards, active learning exhibited by students, and definitive feedback on performance. Ewell (1991) also indicated the two remaining reports, *Integrity in the College Curriculum* and *To Reclaim a Legacy*, relayed themes tied to curriculum and assessment. Ewell (1991) summarizes, "Here, the curricular connection to assessment lies largely in the felt need for the intensive, integrative demonstrations of student knowledge and capacities...to complete and certify the process of undergraduate instruction" (p. 78).

The overall intent gleaned from these 4 reports and described in more detailed in the literature review was not a public mandate for outcomes-based testing in higher education as was arising in the K-12 system, but rather to encourage a move away from traditional accountability measures such as institutional accreditation as the sole indicator of institutional quality (Ewell, 1991). Although somewhat vague in form, the kinds of assessments called for in these reports required the results of assessment be

immediately useful in structuring academic interventions. A substantially new approach to assessment was called for as a major premise of this higher education reform movement. This approach indicated a transition to learner-centered environments with frequent feedback for learners, teachers, and institutions to make improvements (Ewell, 1991; Huba & Freed, 2000).

Peterson and Einarson (2001) found that after more than a decade of assessment scholarship activity, the majority of institutions included in their study have adopted very limited approaches to student assessment. In addition, these institutions have developed a select few institutional mechanisms to support and promote assessment while failing to monitor the uses and impacts of these assessment efforts (Peterson & Einarson, 2001). Peterson and Einarson (2001) also found

On the whole, institutions emphasize the collection of easily quantifiable post college measures, such as employment outcomes and further education, over more complex measures, such as higher-order cognitive skills and affective development. They make greater use of traditional assessment methods, such as standardized instruments, than less traditional methods, such as portfolios or capstone courses (p. 655).

These easily aggregated assessments, much like state and national assessments may provide a big picture of descriptive elements as well as issues and gaps in achievement, but they do not tell us what students really know. These assessments reduce all learning to multiple choice formats, and typically are now dictating how and what is taught. In addition, content is so narrowly focused that no insight is provided into how students are truly performing (Ewing, 1998; Stiggins, 2004). While these forms of assessment are not going to disappear, teachers who have a broader knowledge base with respect to

assessment have the ability to assess students' knowledge, skills, and abilities more comprehensively.

Stiggins (1999) calls for a re-emphasis on classroom assessment. Stiggins argues that "...if assessment is not working effectively in our classrooms every day, then assessment at all other levels (district, state, national, international) represents a complete waste of time and money" (p. 193). Current reform in higher education indicates a shift from teaching to learning. This shift requires a re-evaluation of the role of the learner and the role of the teacher. Teaching habits, assumptions related to learning, and especially the role and form of assessment will require a paradigm shift to stimulate a learner-centered culture (Barr & Tagg, 1995; Huba & Freed, 2000).

Alternative assessments, assessments which are alternative to high stakes testing, provide an opportunity to formalize assessment that does not adhere to the traditional notion of standardization, efficiency, cost-effectiveness, objectivity, and machine scorability. An alternate definition of authentic or alternative assessment is defined as including tasks that are contextualized, complex, and challenging (Wiggins, 1989). Labels for alternative assessment often include but are not limited to performance assessment, authentic assessment, situated assessment, dynamic assessment, and assessment by exhibition (Garcia & Pearson, 1994). Findings reported within Garcia and Pearson's review of the literature suggests that teachers committed to the use of alternative assessment often improve their students' performance when support and guidance is provided as needed. Another key finding is alternative assessments are a way to establish equity; equity in which students are given the opportunity and the means to put forth their best effort. These various forms of alternative assessment allow

for flexibility and diverse ways of problem solving and task completion (Garcia & Pearson, 1994).

Black and Wiliam (1998) indicate sampling students' achievement specifically through short exercises taken under the restraints of formal testing is "fraught with dangers" (p. 148). There are often threats to validity as conditions under which formal testing occurs are very different from those of everyday activity. Collaborative work is frequently essential or even required in everyday life but is forbidden under the conditions and restraints of formal testing (Black & Wiliam, 1998). Furthermore, Black et al. (2004) indicate that

Assessment for learning is any assessment for which the first priority in its design and practice is to serve the purpose of promoting students' learning. It differs from assessment designed primarily to serve the purpose of accountability, or of ranking, or of certifying competence. An assessment activity can help learning if it provides information that teachers and students can use as feedback in assessing themselves and one another and in modifying the teaching and learning activities in which they are engaged (p. 10).

A still deeper issue indicated is the learning environment has to be formulated in such a way to involve students more actively in classroom tasks to emphasize students' thinking and make that thinking public (Black, Harrison, Lee, Marshall, & Wiliam, 2004). As such, the connection between learning and assessment is made visible. Assessment is powerful tool that can be used to improve if not transform undergraduate education (Angelo, 1999).

As long as this researcher's focus is tied to both assessment and mathematics, it is essential to include perspective with respect to assessment as stated by the National

Council of Teachers of Mathematics also known as NCTM. NCTM states by using multiple methods of assessment, specifically alternative assessments, all students are given the opportunity to learn and use mathematics successfully (National Council of Teachers of Mathematics, 1989). Additional recommendations proposed by NCTM's *Curriculum and Evaluation Standards* (1989), *Professional Standards for Teaching Mathematics* (1991), and their *Assessment Standards for School Mathematics* (1995) must also be taken under advisement. From the Overview on Evaluation Standards (National Council of Teachers of Mathematics, 1989), "Student assessment will be integral to instruction; Multiple means of assessment methods will be used; All aspects of mathematical knowledge and its connections will be assessed" (p. 190). From Standard 7: Assessing Students' Understanding of Mathematics (National Council of Teachers of Mathematics, 1991),

Teachers will use a variety of assessment methods to determine students' understanding of mathematics; Teachers will align assessment methods with what is taught and how it is taught; Teachers will analyze individual students' understanding of, and disposition to do, mathematics so that information about their mathematical development can be provided to the students, their parents, and pertinent school personnel (p. 110).

Finally, from the Inferences Standard (National Council of Teachers of Mathematics, 1995), "Assessment should enhance mathematics learning; Assessment should promote equity; Assessment should be an open process; Assessment should promote valid inferences about mathematics learning; Assessment should be a coherent process" (p. 19).

Assessment should be viewed as an opportunity to gather information and insight about our students and their learning. It should be embedded into every aspect of the teaching and learning process. The culmination of formative and summative assessment allows teachers to assess their teaching as well as the students' learning. For the last two decades, the mathematics educational community as directed by NCTM has made a determined effort to address the various problems with respect to mathematics education. Unfortunately, the literature shows there are doubts with respect to the role of alternative assessment and its place in higher education while at the same time indicating the need for alternative assessments to enhance and improve student learning at all grade levels including higher education. What is now required is a body of evidence in higher education to support this cultural shift from assessment of learning to assessment for learning.

A review of the literature for higher education within multiple databases indicates the terms alternative assessment, authentic assessment, and performance assessment are indeed frequently interchanged based on key wording searches. For the purpose of this study, the term alternative assessment will be used to when referencing assessments as described above which are alternative to standardized, norm referenced, multiple choice testing. While the term alternative assessment is broad, alternative assessments can be examined within some central themes. Many forms of these assessments insist upon reflective components or require students to demonstrate a specific skill. As such, alternative assessments are easier to describe if grouped within the following categories: ongoing/reflective, content related assignments, culminating/synthesis experience, and exhibitions (Davies & Wavering, 1999).

As described by Davies and Wavering (1999), ongoing or reflective assessments illustrate or monitor changes or growth in the students' thinking process. These assessments include but are not limited to journals, one minute papers, and threaded discussions. Content related assignments are assessments that evaluate students' skills or products which are essential to mastery of the course content. These assessments are often completed as a combination of self-, peer-, and teacher assessment which include cooperative learning or group work, project components, and transform representation of knowledge to another mode to check for understanding. Per Davies and Wavering (1999), culminating or synthesis experiences may be either formative or summative in nature. These assessments are utilized to represent students' growth via artifacts. Portfolios are the most common and frequently use culminating/synthesis assessment. Exhibitions as assessments require students to give a public presentation while integrating content and/or skills from the course. Students' competence while presenting to a real audience during the assessment is considered to be one of the most crucial components of the assessment (Davies & Wavering, 1999).

With respect to learning mathematics, many students seem to interpret learning as memorizing facts and algorithms. Students rarely expect to draw meaning from their undertakings and cannot see mathematics as being a creative endeavor. Thus, students view mathematics as something they do and infrequently make connections to develop a deeper understanding of the content. When students are engaged in learning and writing where the learner is building connections between what is being learned and what is already known qualifies as *Writing to Learn* (Borasi & Rose, 1989). To truly grasp cognition, metacognition and emotion when learning mathematics, students require skills and encouragement that assist them in building their reflective capabilities.

Writing to Learn is a means to which students can reach a deeper and more personalized approach to learning mathematics (Borasi & Rose, 1989; L. L. Burton, 1984; Clarke, Waywood, & Stephens, 1993; Powell & Lopez, 1989). The aim of this study is to reach a deeper and more personalized approach to learning mathematics with writing as the catalyst for the learning.

Rational for Study

A new vision of assessment has been established. Now a shift needs to be made from assessments that verify learning to assessments that support learning (Stiggins, 2007). Teachers and students must recognize they are partners in the assessment process. Through the use of alternative assessments, students can become both consumers of assessment and self-assessors. Within the mathematics arena, changes are and have occurred with respect to assessment procedures. According to Romberg, Zarinnia, and Collins (1990) in schools today there should be a plan to, “change from drill on basic mathematical concepts and skills to explorations that teach students to solve problems, to communicate, to reason, to interpret, to refine their ideas, and to apply them in creative ways” (p. 22). Assessments which provide not only the number of correct answers, but the thinking that produced those answers needs to be developed and used to focus mathematic instruction on higher order thinking (Romberg, Zarinnia, & Collis, 1990). Multiple articles address the need for change in assessment practices. These articles examine and discuss alternative assessments in mathematics which included journal writing, reflective writing, portfolio assessments both large and small scale in varying disciplines, open-ended problems, interviews, performance assessments, and the use of big ideas to build assessments (Asturias, 1992; Bailey &

Chen, 2005; Berenson & Carter, 1995; Cicmanec & Viechnicki, 1994; Niemi, Vallone, & Vendlinski, 2006; Sen, 1998). While all of these articles contribute to the alternative assessment literature, they also demonstrate there is still a need for more empirical data in this arena as there is a lack of research studies on alternative assessments in higher education. Further examination of additional studies with an emphasis on *Writing to Learn Mathematics* also indicates the need for more empirical data. A small group of studies advocate the benefits of *Writing to Learn* activities in the mathematics classroom, but maintain some of the focus on describing the type and use of the writing rather than the learning outcomes for students (Borasi & Rose, 1989; Clarke, et al., 1993; DiBartolo, 2000; Miller, 1992; Powell & Lopez, 1989; Reilly, 2007).

This mixed methods study addressed the effectiveness of *Writing to Learn Mathematics* by examining the effects of introducing various forms of writing into a Trigonometry course and evaluating students' academic achievement. In addition, this mixed methods study addressed the use of writing as an assessment tool to incorporate reflective activities for undergraduate students enrolled in a community college Trigonometry course to promote both conceptual and metacognitive growth. A triangulation mixed methods design was used a type of design in which different but complementary data are collected on the same topic (Creswell & Plano Clark, 2007). This study used a cross-over design to test the use and application of this alternative assessment in higher education and predicted that the use of *Writing to Learn Mathematics* would positively influence the overall achievement for students enrolled in a Trigonometry course. Concurrent with this data collection, student writing excerpts were examined to explore conceptual and metacognitive growth for students enrolled in the Trigonometry course. The collection of qualitative and quantitative data brings

together the strengths of both forms of research to investigate the effects of reflective writing activities on students' metacognitive and mathematics conceptual growth in addition to their overall mathematics achievement.

Purpose of the Study

The purpose of this study was to investigate the overall effect of using an intervention *Writing to Learn* in a mathematics course, specifically Trigonometry, at the community college level. The intent of the study was to provide additional empirical evidence to the literature demonstrating students' overall academic achievement as well as their mathematics conceptual growth in addition to their metacognitive growth by using *Writing to Learn Mathematics*. This study was an attempt to use writing in mathematics to deepen students' learning by encouraging students to become more self-reflective about their approach to learning mathematics.

Research Questions

The primary research question for this study was:

How does writing to learn mathematics as an assessment tool in a Trigonometry course relate to overall achievement and self-reflection with respect to learning mathematics?

Specifically,

1. What types of students are enrolled in these two sections of Trigonometry and how are the students in the course similar/ different with respect to background, mathematical ability, and experience with *Writing to Learn Mathematics*?

2. Is there a significant difference in student exam scores for the portion of the course where students experience *Writing to Learn Mathematics* versus the portion of the course where students do not experience *Writing to Learn Mathematics*?
3. What is the nature of students' individual metacognitive functioning and in what ways does this change during the course of this study as students utilize various writing activities which engage students in individual reflective writing as part of the course?

Definition of Terms

The language of assessment can be somewhat convoluted, so clarifications must be made with respect to definitions used in the language of assessment. The National Center for Research on Evaluation, Standards, & Student Testing (CRESST) provides an exhaustive glossary of terms. As one of the leaders in the alternative assessment movement, these definitions have been and continue to be used by the research community examining alternative assessment (National Center for Research on Evaluation).

Alternative Assessment (also authentic or performance assessment): An assessment that requires students to generate a response to a question rather than choose from a set of responses provided to them. Exhibitions, investigations, demonstrations, written or oral responses, journals, and portfolios are examples of the assessment alternatives we think of when we use the term "alternative assessment." Ideally, alternative assessment requires students to actively accomplish complex and significant tasks, while bringing to bear prior knowledge, recent learning, and relevant skills to solve realistic or authentic problems. Alternative assessments are usually one key element of an assessment system.

Assessment: The process of gathering, describing, or quantifying information about performance.

Assessment System: The combination of multiple assessments into a comprehensive reporting format that produces comprehensive, credible, dependable information upon which important decisions can be made about students, schools, districts, or states. An assessment system may consist of a norm-referenced or criterion-referenced assessment, an alternative assessment system, and classroom assessments.

Classroom Assessment: An assessment developed, administered, and scored by a teacher or set of teachers with the purpose of evaluating individual or classroom student performance on a topic. Classroom assessments may be aligned into an assessment system that includes alternative assessments and either a norm-referenced or criterion-referenced assessment. Ideally, the results of a classroom assessment are used to inform and influence instruction that helps students reach high standards.

Criterion-Referenced Assessment: An assessment where an individual's performance is compared to a specific learning objective or performance standard and not to the performance of other students. Criterion-referenced assessment tells us how well students are performing on specific goals or standards rather than just telling how their performance compares to a norm group of students nationally or locally. In criterion-referenced assessments, it is possible that none, or all, of the examinees will reach a particular goal or performance standard. For example: "all of the students demonstrated proficiency in applying concepts from astronomy, meteorology, geology, oceanography, and physics to describe the forces that shape the earth."

Evaluation: When used for most educational settings, evaluation means to measure, compare, and judge the quality of student work, schools, or a specific educational program.

Norm-Referenced Assessment: An assessment where student performance or performances are compared to a larger group. Usually the larger group or "norm group" is a national sample representing a wide and diverse cross-section of students. Students, schools, districts, and even states are compared or rank-ordered in relation to the norm group. The purpose of a norm-referenced assessment is usually to sort students and not to measure achievement towards some criterion of performance.

Two additional definitions may also prove useful. The concepts of formative and summative assessment are also frequently mentioned in the assessment literature.

These particular definitions were created by the National Research Council for

classroom assessment and science education (National Research Council, 2001). Similar definitions can also be found in the *Classroom Assessment Techniques* (Angelo & Cross, 1993) and from the article *Inside the Black Box: Assessment for Learning in the Classroom* (Black, et al., 2004).

Formative assessment: Refers to the assessments that provide information to students and teacher that is used to improve teaching and learning. These are often informal and ongoing, though they need not be. Data from summative assessments can be used in a formative way.

Summative assessment: Refers to the cumulative assessments, usually occurring at the end of a unit or topic coverage, that intend to capture what a student has learned, or the quality of the learning, and judge performance against some standards. Although we often think of summative assessment as traditional objective tests, this need not be the case.

Assessments which are alternative in nature can fall under either formative or summative depending on their function.

Because the terms summative assessment and evaluation can at times be interchanged, further discussion of these two terms is warranted. According to Suskie (2009), Evaluation is defined in many different ways. One definition equates evaluation with judgment. Evaluation is using assessment information to make an informal judgment on such things as whether students have achieved pre-established learning goals, the relative strengths and weaknesses of our teaching/learning strategies, or what changes in our goals and teaching/learning strategies might be appropriate. This definition points out that assessment results alone only guide us; they do not dictate decisions. A second definition of evaluation is determining the match between intended outcomes and actual outcomes. Under this definition, assessment of student learning and evaluation of student learning could be considered virtually synonymous. A third definition of evaluation is investigating and judging the quality or

work of a program, project, or other entity rather than student learning. Under this definition, evaluation is a broader concept than assessment. While assessment focuses on goals for student learning, evaluation also address all the major goals of a program (Suskie, 2009). Suskie (2009) additionally describes summative assessments as those which are obtained at the end of a course or program. Their purpose is usually to document student learning for transcripts and for employers, donors, legislators, and other external audiences. Students may not receive any feedback on their performance other than possible an overall grade (Suskie, 2009). For clarification purposes for this study, this researcher expands the previous definition for evaluation to the following.

Evaluation: Evaluation is using assessment information to make an informal judgment on such things as whether students have achieved on pre- established learning goals, the relative strengths and weaknesses of our teaching/learning strategies, or what changes in our goals and teaching/learning strategies might be appropriate (Suskie, 2009).

Finally, a definition for metacognition is needed. Discussion of this term as well as alternate definitions for metacognition appears in the literature review.

Metacognition: Metacognition refers to one's knowledge concerning one's own cognitive processes or anything related to them, e.g., the learning-relevant properties of information or data (Flavell, 1979).

Flavell further divides metacognitive knowledge into three categories: knowledge of person variables, task variables and strategy variables. Thus metacognitive processes are central to planning, problem-solving, evaluation and many aspects of language learning. Activities such as planning how to approach a given learning task, monitoring comprehension, and evaluating progress toward the completion of a task are metacognitive in nature (Flavell, 1979). In this study, metacognitive functioning or metacognition is understood to be metacognitive actions, behaviors, and decisions

exhibited and expressed through writing and will not be limited only to problem solving activities.

Because mixed methods research is not as common as qualitative or quantitative researcher, a definition of this form of researcher should also be included. As defined by Johnson & Onwuegbuzie (2004),

Mixed methods research: The class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study.

Assumptions and Limitations

Due to the quasi-experimental nature of this study, there were threats to internal and external validity that must be addressed. The researcher was the instructor of record for both sections of the course used for the study. As students chose to enroll in the section that best meets their needs, purely random assignment to sections was not an option. Random assignment of the order of the intervention was utilized for the within subjects cross-over design. The intervention was administered by the researcher and thus may incorporate bias as the researcher has piloted this intervention multiple semesters and feels the intervention promotes students' conceptual and metacognitive growth. While these factors affect the generalizability of the study, high ecological validity was maintained. An additional concern was tied to students knowing they were part of a study. Students were made aware of the study and had the option of opting out of the study. The student data included varied as it was used for the researcher's study, for institutional data, and for determining course grades. Only those who consented to participate were included in the researcher's study. Thus while the assessments included in the course were part of the course, regardless of the study, some

students may have felt the writing was extra work. Students may have decided to participate minimally in the writing portion of study for various reasons even with an adverse effect on their grade. Based on these negative feelings, there could have been a carryover of this negativity into their writing resulting in a poor response rate which is an additional threat to external validity. Additionally, when the intervention was discontinued for the first group, students may have chosen to continue to use *Writing to Learn Mathematics* even though they were not required to do so for the course resulting in another form of carryover and yet another threat to external validity.

As for threats to internal validity, equivalence of groups had to be addressed. An effort was made to determine that the two groups were approximately equal prior to the intervention. Both beliefs and attitudes toward mathematics as well as trigonometric content knowledge were examined. The type of students enrolled in community college trigonometry was assumed to be approximately equal based on the type of students who enroll at community colleges, the necessary prerequisites to enroll in trigonometry, and the intended major of the students. Grades from previous courses, ACT scores, and demographic information were evaluated with respect to equivalence of groups. In addition, a certain amount of experimental mortality was expected due to the nature and difficulty level of the course.

An additional concern related to the study was the contamination of the first intervention group. As such, the researcher who was also the faculty member assigned to the course for the duration of the study asked students to refrain from using *Writing to Learn Mathematics* until directed to do so again at the end of the term. Based on this researcher's conceptual framework for the study, this was both a challenge and a frustration. A second concern was sample size and provided the rationale for using a

cross-over design rather than a treatment and control group design. This was to ensure that the intervention was actually taking place in the manner necessary for the study and also clarified reasoning for the researcher's choice of using classes which she was teaching. The institution at which the study took place only offers two sections of Trigonometry every spring term so additional sections were not available for inclusion in the study.

Delimitations

As for delimitations, the study was conducted at only one community college and used two courses in northern Colorado with one instructor. As such, the sample size resulted directly from the number of students enrolled in only these two sections of the course. The duration of the study was for one semester. Multiple sections of the course are offered only spring term which allowed the researcher to conduct the study within only one term rather than extending the study over an academic year.

Researcher's Perspective

The inspiration for this study was two-fold. This researcher's support and continued confidence for alternative assessments and metacognitive interventions in mathematics came as a direct result of involvement with The Center for Teaching and Learning in the West (CLT-West) and personal experiences as a college faculty member using alternative assessments in higher education. CLT-West is a consortium of five institutions of higher learning in the western United States, including Colorado State University. The National Science Foundation (NSF) established Centers for Teaching and Learning to foster science and mathematics teaching development and research. In particular the goal for CLT-West is to develop and support a new generation of national

educational leaders. These leaders are to use their knowledge of mathematics, science, and pedagogy to better serve teachers and students in the high needs schools.

At Colorado State University, members of the CLT-West organization chose to conduct a systematic review of mathematics interventions with at-risk students. For this systematic review, conducted primarily by James Dugan, the problem statement for his study, as originally proposed by Brian Cobb and Paul Kennedy (personal communications, August 12, 2004) to Elizabeth Swanson, Director of CLT-West, was as follows: "What are the characteristics of curricular and/or instructional interventions that are most effective in reducing (or reversing) the mathematics achievement gap for secondary students who are at greatest risk of school failure?" (Dugan, 2007). In particular, one of his research questions focused on instructional interventions that were most effective in reducing the achievement gap for mathematics. The results of Dugan's study show a sub-grouping of three potentially effective interventions: (a) cognitive and metacognitive strategies; (b) cooperative learning; and (c) peer tutoring.

From piloting elements of this research projects conducted in my community college classrooms all having the goal of improving student learning, I also determined that the most successful interventions were a result of metacognitive strategies incorporated into mathematics courses. I feel that NCTM's mission extends to students beyond the secondary classroom, and it is the responsibility of every teacher at every level to promote and enhance student learning. As assessment of students is integral to students' conceptual and metacognitive growth, my efforts to expand and promote alternative assessment in higher education will continue. I believe the most effective assessments require engaging students in their learning process and alternative assessments such as *Writing to Learn Mathematics* does just that.

During the last thirteen years of teaching at the community college level, this educator has transitioned from using a very traditional approach to assessing mathematics otherwise known as the “homework-test model” to more varied approach which includes both formative and summative assessments such as portfolios, *Writing to Learn Mathematics*, board work models, and course projects. While at times I still utilize pencil and paper exams as the primary mode for evaluating students’ learning, I feel these alternative assessments better represent the students’ mathematical abilities, conceptual growth, and self-reflection with respect to learning mathematics. Students can communicate their misconceptions, convey understanding, make connections, and articulate their needs as learners more clearly as a result of using these various assessment techniques. In addition, I find that many adult learners bring anxiety and fear into the classroom as a result of a previous negative experience with learning mathematics. High stakes testing situations can and frequently do fuel these anxieties to create an environment which inhibits learning. In my experience, using alternatives to high stakes testing has allowed not only these types of students but all students to demonstrate in various ways what they know, can do, and understand.

CHAPTER 2: LITERATURE REVIEW

This chapter provides discussion around issues with assessment in higher education. First the literature on the current state of mathematics in the United States, alternative assessment in general, and the assessment needs of adult learners is examined to look at issues and problems with traditional approaches to assessment in mathematics. In addition, the foundation for writing as a mode of learning is detailed with connections to the *Writing Across the Curriculum* and *Writing to Learn* movements. Finally, writing and its connection to learning mathematics is explored to describe how writing can benefit the learning of mathematics. To better represent the organization of the chapter, a map of the literature review is provided in Figure 1.

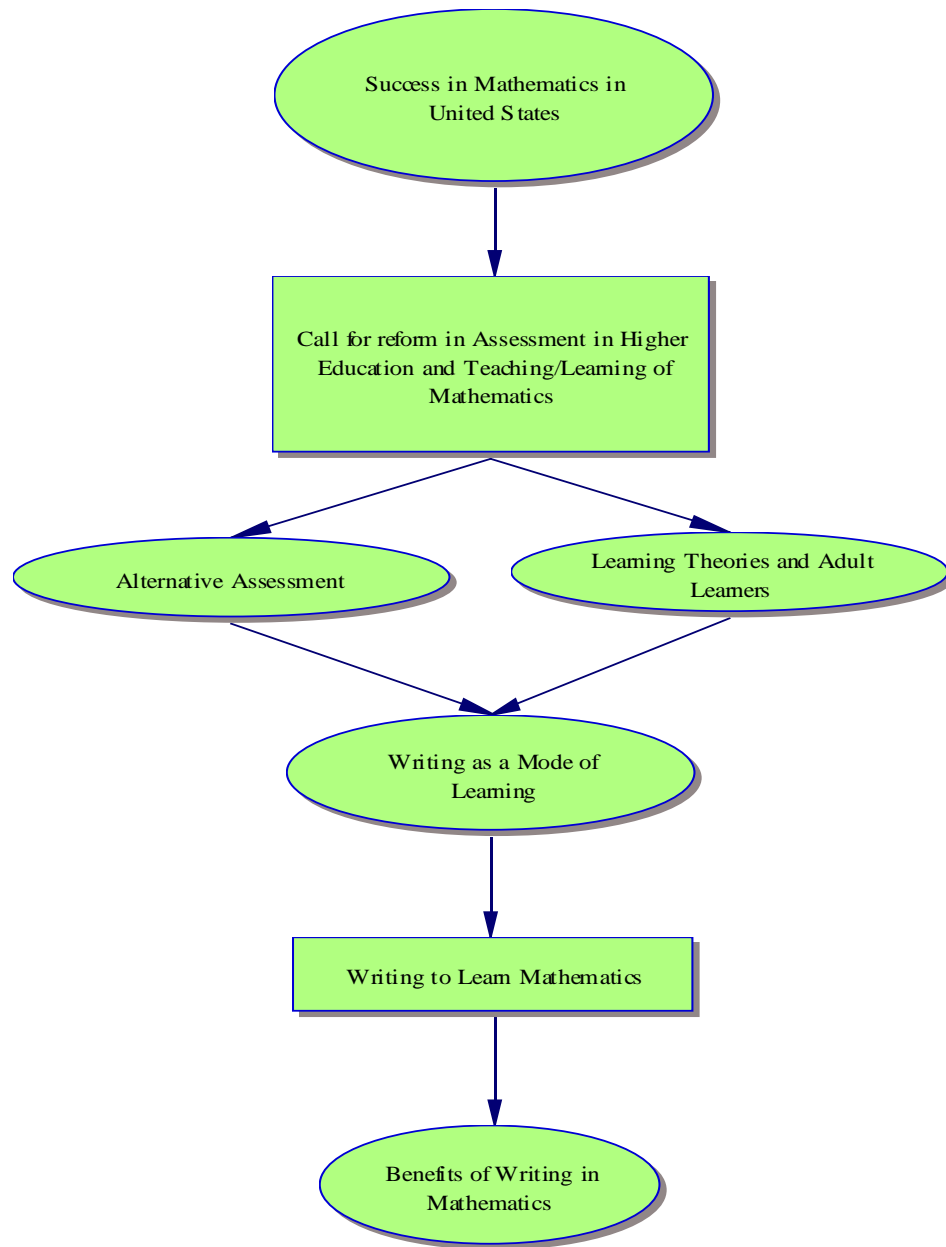


Figure 1. Map of the Review of the Literature

Introduction

The United States has been a leader in higher education for decades. Countries from around the world have often sent their students to the U. S. for a better education. The current state of the higher education system in the U.S. tells another story. Once a

global leader for careers in science, mathematics, and engineering related-fields, statistics from the year 2004 show the U.S. at the bottom of the list of Group of Eight (G-8) countries. These countries include Canada, France, Germany, Italy, Japan, and the United Kingdom along with the United States. The most current data available from the National Center for Education Statistics shows overall degrees awarded in science, mathematics, and engineering related-fields were at 17% in 2004 for the U.S. while the other G-8 countries range from 20% to 30% (National Center for Educational Statistics).

“College readiness” is tied to success in higher education including success in mathematics courses beyond this first college level mathematics course, College Algebra, and degree completion with science, mathematics, and engineering majors. College readiness is defined by American College Testing Program (ACT) as credit bearing college-entry level courses. Because success in mathematics is fundamental to graduating with a career in these majors, college readiness can influence career paths. Based nationally on 1, 480,469 students in 2009, the current state of readiness in mathematics, specifically College Algebra was as follows: 50% of White or Caucasian students ready for College Algebra, 12% of African American students, 27% Hispanic of students, 65% Asian American of students, and 24% of American Indian/Alaskan Native students ready for College Algebra. Overall only 42% of this group was ready for college level mathematics in 2009 (American College Testing Program). ACT data also showed that students are losing momentum in high school for college readiness as a result of less rigorous courses and a gap between postsecondary expectations related to what high schools are teaching and assessing. One of the recommendations for bridging the gap between institutions of higher education and high schools is to use both formative and summative assessments that improve both teaching and learning. These

assessments must be aligned with college readiness and should be related to expectations for assessment in higher education (American College Testing Program).

Assessment in Higher Education

Based on the assessment reform explosion of the mid 1980's and its persistence through the early 1990's, policy makers in higher education and secondary education have expressed both a need and a preference for assessments which use higher level thinking and/or problem solving skills that also measure metacognitive, collaborative, and interpersonal skills. Assessments such as these are used to directly inform instruction as well as ask students to perform a task, produce a product, or create an artifact. Additionally, assessments of this nature frequently evidence real-world applications as well as use tasks that represent meaningful instructional activities. Assessments such as those described above are frequently characterized as alternative assessments as they are an alternative to standardized, norm referenced, multiple choice testing (Herman, Aschbacher, & Winters, 1992; Linn, 1993; Wiggins, 1989). According to Herman et al. (1992), while the terms alternative assessment, authentic assessment, and performance assessment are interchanged, the significance of these types of assessments is that students are required to generate a response rather than simply choose an available option.

During the last 20 years and still very prevalent today are two distinct paradigms of assessment. According to Ewell (2008), the first paradigm is best described as the improvement paradigm. This approach to assessment is considered learning centered and is a result of two reports from the mid 1980's. *Involvement in Learning* (National Institute of Education, 1984) and *Integrity in the College Curriculum* (Association of

American Colleges, 1985) insist that to improve undergraduate curricula and pedagogy (andragogy) institutions must have a way to provide systematic evidence to show what and how much students learn. Per Ewell (2008), a second divergent paradigm also exists which can be considered the accountability paradigm. This institution centered approach to assessment has a foundation based in the 1986 report *Time for Results* (National Governors' Association, 1986). This report called for public institutions of higher education to examine what graduating students know and can do to determine the effectiveness of the public's investment in higher education by collecting and reporting on student academic achievement. Over time, the improvement paradigm continued to lose ground while the accountability paradigm continued to gain momentum. Major recessions, accreditation, and stimulus funding (Ewell, 2008) are all contributing factors to the accountability paradigm's prevailing approach. Based on the nature of institutional compliance under the accountability paradigm, it is difficult for a culture of evidence for continuous improvement to co-exist within this paradigm. This scenario also explains the absence of significant and substantial findings in the research literature over the last 10 years under the umbrella of alternative assessment in higher education.

Assessment reform along the improvement path has experienced a recent resurgence. In 2006, a report titled *A TEST OF FUTURE LEADERSHIP: Charting the Future of U.S. Higher Education* was commissioned by Margaret Spellings the former Secretary of Education. This reported concluded that U.S. higher education "needs to improve in dramatic ways". Higher education systems in other nations are rapidly improving and making visible the short-comings of the state of postsecondary institutions in the U.S. Due to the extensive research compiled within this report, the

following recommendation was made with respect to innovation (U.S. Department of Education, 2006).

We recommend that America's colleges and universities embrace a culture of continuous innovation and quality improvement. We urge these institutions to develop new pedagogies, curricula and technologies to improve learning, particularly in the areas of science and mathematics. At the same time, we recommend the development of a national strategy for lifelong learning designed to keep our citizens and our nation at the forefront of the knowledge revolution (p. 5).

Additional recommendations made by the commission urge institutions of higher education to adopt instructional practices based on learner-centered principles. These practices are connected to yet another fundamental framework for higher education developed by Arthur Chickering and Zelda Gamson. Chickering and Gamson (1987) draw from research on good teaching and learning in colleges and universities that represent good practice in undergraduate education. As such, seven learner-centered principles which include the following: encourages contact between students and faculty, develops reciprocity and cooperation among students, encourages active learning, gives prompt feedback, emphasizes time on task, communicates high expectations, and respects diverse talents and ways of learning also lay the foundation for learner-centered principles (Chickering & Gamson, 1987). According to Chickering and Gamson (1987), to respect diverse talent and ways of learning, requires students be given the opportunity to demonstrate their talents and learn in ways which best suit the learners. Once students gain confidence in these learning scenarios, they can be pushed

outside of their comfort zone to learn in ways that may be more challenging to them.

Additionally, two principles, encourages active learning and gives prompt feedback, are directly connect the assessment process and necessitate the utilization of alternative assessments.

Alternative Assessment

The primary goal of assessment is not limited to the acquisition of content knowledge. Assessment no longer implies that an individual must “take a test” alone in a timed, scheduled, paper-pencil environment (Romberg, 1992; Wiggins, 1993).

Assessment takes place in many contexts, includes both individual and group work, can be opened ended, have aided or unaided response, and employ time restrictions or not.

Because assessment is an integral part of instruction, instructional goals must be considered when designing meaningful assessment tasks (Garcia & Pearson, 1994; Herman, et al., 1992; Wiggins, 1989; Wiggins & McTighe, 2005). The promotion of in-depth learning requires students to think about “the what” and “the why” related to their learning. Integrating knowledge into current schema within the learners’ mind requires performance in increasingly challenging environments. Learners must think about the tasks and not focus on isolated skills and facts. The performance of meaningful complex tasks in increasingly challenging environments ensures student motivation and encourages confidence building. Meaningful learning is seen as intrinsically motivating and leads to long term mastery (Herman, et al., 1992). Linking assessment to real-world events, allowing students to collaborate with others, and applying interdisciplinary and/or previous knowledge will fundamentally link assessment with the broader social context students live. Thus these assessments allow students to acquire key concepts and processes for communicating, building, and using

knowledge (Shepard, 2000). Alternative assessments require deep learning from students. Some common characteristics in alternative assessment are as follows: ask students to perform, create, produce, or do some task; tap higher level thinking and problem solving skills; use tasks that represent meaningful instructional activities; invoke real-world applications; people not machines, do the scoring using human judgment; require new instructional and assessment roles for teachers (Herman, et al., 1992). These forms of alternative assessments have the utmost goal of examining the process of learning as well as products of learning. Standardized tests and teacher made pencil-and-paper test do not fall in the category of alternative assessment. In addition, test bank and test materials packaged with the curricular materials are almost never alternative in nature.

In relation to alternative assessments, there are some instructional objectives which require product evaluations and others that require performance evaluations. These types of objectives cannot be directly assessed by pencil-and-paper test. The product itself must be evaluated (Thorndike, 1997). Some examples of product assessments include penmanship activities, cooking a meal in a foods course, constructing a bookshelf in woodshop. Students are required to produce a product that meets certain criteria and acceptability standard. For performance assessments, a student is asked to carry out a procedure or actually perform. These kinds of scenarios do not leave a tangible product that can be assessed (Thorndike, 1997). The processes used to obtain the final product are what are being assessed. Some examples of these assessments are oral reports or project explanations, acting out a scene in a play, playing a piece of music, or carrying out some procedure. It is essential that criteria are developed for discriminating different degrees of competency in the performance which

can be evaluated using a rubric. The following lists separate process and product forms of assessments. These assessments are different in nature and so must be the evaluation tool. To assess processes a teacher may use alternatives like interviews, document observations, have students create learning logs, perform self-evaluations, or hold debriefing interviews following a project or demonstration (Herman, et al., 1992). To assess products a teacher may use essays or projects with specific criteria, student portfolios with specific elements, student demonstrations or investigations, artistic performance or exhibition (dance, painting, drama scene), surveys, or true/false or multiple choice exams with explanation sections (Herman, et al., 1992).

It is often the case that we teach the way we do out of habit or tradition. Often we teach a concept the same way it was taught to us. We also teach conveniently, meaning that we use measurement or evaluation techniques that do not involve flexibility (Huba & Freed, 2000). Students are given grades based on an arbitrary scale giving an illusion of precision when the scores are actually arbitrary. Good teaching should not produce a bell-shaped curve or high variability. It should reduce it. Learning outcomes do not have to be quantified nor do they need to be considered correct or incorrect (Biggs, 2001). Students need to see connections to the whole picture not simply fragments of coursework poorly pieced together. To apply meaning to various parts of a course, formative assessments must be in place to enhance the analytical/statistical assessments. This will allow the teacher and the student the opportunity to integrate all parts of the course: procedural, conceptual, theoretical, and performance. These formative assessments are frequently alternative assessments by their very nature (Herman, et al., 1992).

Classroom assessment not only provides feedback about student learning, it also provides feedback about instruction and allows for modification of instruction. A blending of formative and summative assessment in the classroom will provide teachers with a better picture of their instruction and students' understanding of their teaching (Angelo & Cross, 1993). Teaching is all about communicating. It takes place in a social setting that must allow students to assess their own learning and our teaching through the lens of their own perspective. For students to grow and develop self-awareness about their learning there must be critical reflection and critical self-reflection (Cranton, 2001). To truly assess what learning is taking place in the classroom a blending of formative and summative assessment approaches is not only beneficial but necessary (Angelo & Cross, 1993).

Adult Learners

To add significance to the information related to alternative assessment and assessment reform, it is essential to examine components tied to adult learning theory. While there are adolescents in college classrooms, the vast majority of students are adults, and their needs when it comes to learning must be considered. Credit for delineating differences between adult and child/adolescent learners resides with Malcolm Knowles. Knowles was one of the first to study adult learners and their education. As a result of his work, andragogy is the term referenced when focusing on the instruction and needs of adult learners (Merriam & Caffarella, 1999; Smith, 2002).

Knowles' model for andragogy includes four assumptions (Knowles, 1973). The first assumption based on maturity or changes in self-concept. Self-concept moves from a dependent personality toward a more self-directed person based on maturation. Second assumption, according to Knowles (1973), adults expand their "reservoir" of

experiences which provide a meaningful source of learning. Third is a readiness to learn in which developmental tasks connected to social roles are strongly tied to the readiness of an adult to learn. Fourth is the orientation to learning and is based on the immediacy of knowledge application. It is critical to bear in mind that adults are more problem-centered than subject- or content-centered when it comes to learning (Knowles, 1973). Finally, adult educators must also consider internal factors which drive adults to learn rather than external motivators. In short, the learning process should be emphasized rather than the content (Kearsley, 2010; Knowles, 1973; Merriam & Caffarella, 1999).

In addition to Knowles' model, four additional models have also influenced approaches to working with adult learners. Cross's characteristic of adult learners (CAL) model, McClusky's theory of margin, Knox's proficiency model, and Jarvis's learning process are all models tied to adult learning theory. While these models offer additional insight into adult learning and maintain a common focus on the characteristic and life situations of adult learners, andragogy remains the best-known model of adult learning (Merriam & Caffarella, 1999). Although Cross's model focuses on personal characteristics rather than learning, the model still provides a framework for thinking about what and how adults learn and integrates elements from other adult learning theories including Knowles' theory of andragogy (Kearsley, 2010). According to Cross (1981), the CAL model provides a framework for thinking about what and how adults learn. The model consists of two classes of variables which are personal characteristics and situational characteristics. Personal characteristics include physical, psychological, and sociocultural constructs while situational characteristics include variables which are unique adult learners (Cross, 1981). An example of this would be a part-time student rather than a full-time student. A flaw in this model, as stated by Merriam and

Caffarella (1999), is its focus on characteristics of adults. There is little detail to describe how adults actually learn or if they do indeed learn differently than children. In addition, the constructs of personal characteristics are not solely characteristics of adult learners.

McClusky's theory of margin also examines a combination of personal and situational characteristics when combined focus on adult development and timing of learning rather than emphasizing the learning process for adults. Much like Vygotsky's Zone of Proximal Development Knox's proficiency theory centers on what an adult learner currently knows and where the learner needs to reach. Given this information, instruction is emphasized rather than focusing on the needs of the adult learner.

McClusky's theory states that adults grow and mature through the interaction of two key components: load and life. Load consists of demands made upon the individual both by oneself and societal demands which require the individual's energy and vitality. Power is a combination of internal or external resources that the individual has available to sustain the load. While examples of power include abilities, aptitudes, skills, possessions, position, and support network, load includes such things as work responsibilities, family commitments, personal goals and emotional stressors. Merriam and Caffarella (1999) raise concerns related to this model for adult learning due to the fact that learning itself has the ability to increase one's power and is not addressed by this model.

Although life events and transitions certainly precipitate many (and some would say the most potent) learning experiences, McClusky's model does not directly address learning itself but rather when it is mostly to occur. One might also question whether a reserve of energy or margin of power is necessary for learning to occur (p. 282).

As stated Merriam and Caffarella (1999), according to Jarvis “All learning begins with experience” (p.283). Jarvis’s model for the learning process delineates nine responses which all focus on both non-reflective and reflective learning. These nine elements include the following respectively: the person, the situation, the experience, the person with reinforced learning but remaining relatively unchanged, practice experimentation, memorization, reasoning and reflection, evaluation, and the person as a changed more experienced individual. The learning cycle which occurs may not result in a person moving through all nine elements of the model as some learning becomes rote and does not lead to future learning. Jarvis’s model, like Knowles, focuses on the learning process rather than other factors. Although his research on this model used adults as subjects with a focus on interactive elements within a social context rather than in isolation, the results once again cannot be limited to only adult learners (Merriam & Caffarella, 1999).

While there is scant empirical evidence to test the validity of the assumptions for andragogy and the additional models, practitioners who primarily interact with adult learners find Knowles’s theory and characteristics for adult learners to provide a better understanding of adults as learners (Merriam & Caffarella, 1999). Illuminating the nuances tied to adult learners is essential in furthering the field for teaching, learning, and assessing adult learners. Included in Knowles assumptions for andragogy, as a person matures his or her self-concept is moved toward one of self-direction. Self-direction for adult learners allows students to take part in discovering their learning needs, creating and incorporating learning experiences, and evaluating and assessing their learning experiences and outcomes. Because the adult learners’ orientation to learning is founded on life experience rather than content experience, adult learners

should be viewed as capable of self-direction and encouraged to take charge of their learning (Barker, Sturdivant, & Smith, 1999).

Adult educators must also consider what makes learning meaningful for adult learners. For adult learners, who they are, the things they value, and how they know the world all intersect to create a basis for learning (English, 2005, December). John Dewey is one of the earliest of progressive educators to write about experience and education. Dewey (1938) determined that education must connect with the learners past real life experiences to propel the learner into the future. He states that experience is a function of the learner, the environment, and the transaction between the two. As such it is the role of the educator to provide a learning environment which provides opportunities for experiences which develop curiosity, strengthen initiative, and promote purpose, growth, and development (Dewey, 1938).

Adult educators have a responsibility to their learners which requires learners to examine and comprehend their patterns of thoughts and actions which can either hinder or nurture their growth as learners. As such it is then necessary to encourage and facilitate reflection and dialogue about meaning and effect of learning experiences (Wilson & Burket, 1989). According to Wilson and Burket (1989), "if learning is to be truly significant, it has to emanate from the individual's reflection and critical examination of his or her response to a learning experience" (p.17). Learner-centered adult education supports the educator as an interventionist. It is the role of such an educator to create learning environments where learners must confront limitations in their own thinking to facilitate grow, self-development, and maturation as a learner (Rossing & Neuman, 1993; Wilson & Burket, 1989). According to Reif (1995) with respect to assessing adult learners, good assessment is often defined by what it is not.

“It is not standard, traditional multiple choice items. If learning is meaningful, it is reflective, constructive, and self-regulated (p.13).” Information is simply not just received when learners know something. They must also interpret and relate the information to previous knowledge to truly know it (Reif, 1995).

Writing to Learn

While the origins of the *Writing Across the Curriculum* (WAC) movement in the United States date back to the late 1800's, the origin is not the focal point of this study. However, it is important to provide a bit of background to show how this movement has permeated higher education for some time. As enrollment grew in higher education during the 1870's, it became apparent that while students were successful in their secondary education and came from some of the best secondary schools in the nation, they were not prepared to write at a college level. With failure rates climbing and the implementation of entrance exams across the nation, a push for more effective writing instruction at the college level resulted in the creation of mandatory freshman level college composition courses (Bazerman et al., 2005; Russell, 1992). Although seemingly widely supported, during the 1930's this course came under fire due to a study conducted by Alvin Eurich at the University of Minnesota. He presented his findings during the National Council of Teachers in English (NCTE) conference in 1931. Eurich shared the results of his study which included the essay works from 54 students before and after freshman level composition. His study showed no significant improvement in the writing of these students after they had completed a three month freshman level composition course. Eurich determined the “habits of written expression” could not be impacted within this short timeframe. He advocated one of the earliest versions of

WAC where English teachers and field based experts collaborate to design writing-based assignments. Though widely discussed and debated by the NCTE, *Writing Across the Curriculum* did not truly take hold until post World War II due to the social political forces at work which resulted in a renewed interest in communication, rhetoric, and writing in the U.S (Bazerman, et al., 2005).

Writing Across the Curriculum (WAC) refers specifically to the pedagogical and curricular attention to writing occurring in university subject matter classes other than those offered by composition or writing programs (most often housed in the English Department). The movement provided systematic encouragement, institutional support, and educational knowledge to increase the amount and quality of writing occurring in such courses as history, science, mathematics and sociology (p. 9).

Writing as a Mode of Learning

With the foundation in place as a result of the WAC movement and the reforms occurring in higher education post WWII, all that was needed was a catalyst to truly ignite a transformation of writing as it was viewed within education. In 1966, a seminar at Dartmouth brought together English language scholars from both the U.S. and Great Britain. During this seminar, the model of language instruction put forth by James Britton and his colleagues and primarily used by the English was shared with the American scholars attending. While the Americans were focused on “disciplinary rigor, standard curricula, and standard ‘objective’ evaluation” (Russell, 1992), Britton et al (1975) identified three types of writing: transactional, poetic, and expressive. Britton and his colleagues determined that transactional writing focused on communication of

information while poetic writing was a forum for the creation of beautiful objects. Expressive writing was for exploring ideas and reflecting upon the writers' thoughts and ideas and the only type of the three truly entrenched in the *Writing to Learn* movement (Britton, Burgess, Martin, McLeod, & Rosen, 1975). As argued by this group, the expressive form of writing can play a pivotal role at every stage of learning and development because it so closely resembles what Vygotsky identified as inner speech. According to Vygotsky (1962), "inner speech, is to a large extent thinking in true meanings" (p. 149). Vygotsky also defined inner speech as speech for oneself. While external speech turns thoughts into words, inner speech reverses the process (Vygotsky, 1962). Expressive writing allows the writer to utilize inner speech in such a way as to get at the heart of what a person is thinking.

As the English explored these three forms of writing, the process-over-product movement emerged in the U.S. as a result of Janet Emig's 1971 publication titled *The Composing Process of Twelfth Graders*. In this landmark work, Emig demonstrated how writing is a complex recursive process. Also influential in the *Writing to Learn* movement was the publication of her article, "Writing as a Mode of Learning". The work serves as an informal platform and can also be considered a charter document for the *Writing to Learn* movement in the United States (Emig, 1977). From the examination of the works of Lev Vygotsky, Jerome Bruner, and Aleksandr Luria, Emig concludes writing requires the brain to function in such a manner that both the right and left hemispheres are engaged. Requiring the processes of analysis and synthesis along with connecting the past, present, and future tenses, writing takes our experiences and makes meaning. As such, Emig details the neuropsychological, integrative, connective nature of writing and discusses how the action of writing allows for immediate review (Emig,

1977). As stated by Emig (1977), “Writing is originating and creating a unique verbal construct that is graphically recorded” (p. 125). Figure 2 demonstrates the correspondence between learning and writing as detailed in Emig’s work.

Selected Characteristics of Successful Learning Strategies	Selected Attributes of Writing, Process and Product
<ul style="list-style-type: none"> • Profits from multi- representational and integrative re-inforcement • Seeks self-provided feedback <ul style="list-style-type: none"> • (a) immediate • (b) long term • Is connective <ul style="list-style-type: none"> • (a) makes generative conceptual groupings, synthetic and analytic • (b) proceeds from propositions, hypotheses, and other elegant summarizers • Is active, engaged, personal-notably, self-rythmed 	<ul style="list-style-type: none"> • Represents process uniquely multi-representational and integrative • Represents powerful instance of self-provided feedback: <ul style="list-style-type: none"> • (a) provides product uniquely available for immediate feedback (review and re-evaluation) • (b) provides record of evolution of thought since writing is epigenetic as process-and-product • Provides connections: <ul style="list-style-type: none"> • (a) established explicit and systematic conceptual groupings through lexical, syntactic, and rhetorical devices • (b) represents most available means (verbal language) for economic recording of abstract formulations • Is active, engaged, personal-notably, self-rythmed

Figure 2. Unique Cluster of Correspondences between Certain Learning Strategies and Certain Attributes of Writing (Emig, 1977)

As there was a lack of empirical evidence to back writing as a mode of learning movement, Newell (1984) examined the effects of note taking, short answer responses, and essay writing on three measures of learning. Recall, concept application, and overall gain in passage-specific knowledge forms of writing were evaluated to determine if one of these forms provided evidence for Emig’s conception of the connective nature of writing. Newell determined essay writing, unlike note taking and short answer responses, required writers to consider information in terms of their own thinking (Newell, 1984). Newell states,

Essay writing, on the other hand, requires that writers, in the course of examining evidence and marshaling ideas, integrate elements of the prose passage into their knowledge of the topic rather than leave the information in isolated bits. This integration may well explain why students' understanding of concepts from the prose passage was significantly better after writing essays than after answering study questions (p. 282).

To provide additional support to this study, Newell and Winograd (1989) re-examined Newell's 1984 data under two new constructs. Additionally from the original study, recall of the theme of expository text along with patterns in students' written responses within the three writing conditions as related to the passages were also re-examined. While reconfirming the original findings, they also determined "analytic essay writing contributed to understanding more than did note taking or responding to study questions" (Newell & Winograd, 1989). Students were best able to find and state the key components in a passage to provide a long term mental model tied to the passage theme as required by the complexity of essay writing. According to Newell and Winograd (1989),

essay writing required more complex manipulation of the overall themes of the passages than did the other two tasks...essay writing requires global planning that entails manipulating the information directly related to more important rhetorical structures, such writing tasks will lead to recall of those structures (p. 211).

Thus, the results of this second phase analysis indicate analytic essay writing requires "a different set of learning and writing operations when compared to the other two tasks" (p.213). Newell and Winograd (1989) determined from their research, writing is rarely

utilized to integrate and consolidate what students take from readings and classroom discussions and should be the focus of future research studies.

During the mid to late 1980's as a result of the indicated research and publications previously mentioned and due to transitions within the *Writing Across the Curriculum* movement from a way to improve exhibition of knowledge to a way for students to work on formulation of meaning, the phrase *Writing Across the Curriculum* was replaced by the phrase *Writing to Learn*. *Writing to Learn* places less emphasis on formal writing or de-emphasizing mastery and focuses on the value of writing and how it contributes to discovery (Connolly, 1989). As stated by William Zinsser (1988), writing is a way to organize and clarify our thoughts. A way to think through a subject and make it our own is a direct result of writing. It forces the writer to uncover what he or she really knows about what is trying to be learned. As we write, we try to experience a moment when we can actually voice what we mean to say in the process of writing to say it (Zinsser, 1988). Therefore, *Writing Across the Curriculum* is not simply learning to write it is also a movement for *Writing to Learn*. Emphasizing *Writing to Learn*, Zinsser conveys that

Through the writing of our students, we are reminded of their individuality. We are reminded, whatever subject we are charged with teaching, that our ultimate goal is to produce broadly educated men and women with a sense of stewardship for the world they live in (p. 48).

More recent research on the *Writing to Learn* front comes in the form of a meta-analysis which examined the research findings about the efficacy of *Writing to Learn* initiatives. A search of multiple databases and a hand search from the Education Index ranging from 1926 to 1998 resulted in 48 studies with treatment-control comparisons

which met inclusion guidelines. Findings of the study are summarized by Bangert-Drowns et al. (2004) as follows:

Writing to learn typically resulted in a small, positive effect of school achievement. Grade level, minutes per writing assignment, and presence of prompts for metacognitive reflection moderated writing-to-learn achievement effects. Treatment length may moderate writing-to-learn effects (p. 49, 51).

In the review, 75% of the outcomes demonstrated benefits of *Writing to Learn* over conventional instruction on equivalent content with a small effect, $d = 0.26$. The writing interventions that included prompts for metacognitive reflection showed the greatest effect indicating that writing has the capability to activate and support metacognition with appropriate integration and cognitive strategy training. In addition, the influence of writing is cumulative. For positive influence on learning to occur as a result of writing, students must become familiar with the tasks and build awareness as to how the practice affects their learning strategies (Bangert-Drowns, Hurley, & Wilkinson, 2004).

Writing to Learn Mathematics

In the process of “doing” mathematics, we are always confronted with the issue of how to communicate our ideas. In doing so, we can’t get away from language whether it is spoken or written, symbolic or descriptive. Mathematics, according to Meier and Rishel (1998), is embedded in language. It is necessary to learn how to make the best use of language (general and mathematical) to express ideas, show precision, and demonstrate value to an audience whoever that audience might be. As such, there is merit in communicating these ideas well (Meier & Rishel, 1998). When students write

about mathematics, they are placing the subject in a context which makes sense to them. This requires students to construct their own meaning through a narrative of writing and speaking mathematics which are central to learning and doing mathematics.

The National Council of Teachers of Mathematics (NCTM) publication *Principles and Standards for School Mathematics* recommends that communication be an essential part of mathematics and mathematics education. Per NCTM (2000), communication is viewed as

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. When students are challenged to think and reason about mathematics and to communicate the results of their thinking to others orally or in writing, they learn to be clear and convincing. Listening to others' explanations gives students opportunities to develop their own understandings. Conversations in which mathematical ideas are explored from multiple perspectives help the participants sharpen their thinking and make connections (p 59).

NCTM feels that dual benefits are provided to students who have “opportunities, encouragement, and support for speaking, writing, reading, and listening in mathematics classes”. Students not only communicate to learn mathematics, they additionally learn to communicate mathematically (National Council of Teachers of Mathematics, 2000). Over the past two decades, a primary focus has been improvement and innovation of mathematics education at all levels and the need continues still. To

embrace a culture of continuous innovation requires structural changes to the present curriculum in mathematics. Exploration, investigation, reasoning, and communication should be the emphasis when providing students the opportunity to learn mathematics (Romberg, 1992).

Using writing to teach and learn mathematics allows students the opportunity to reflect, organize, model, and represent their thinking. A relationship between writing and learning has been long established from the works of Vygotsky and Bruner (as cited in Bazerman et al., 2005; Borasi & Rose, 1989; Clarke, Waywood, & Stephens, 1993; DiBartolo, 2000; Emig, 1977; Powell & Lopez, 1989; Russell, 1992). Additional support and connections between writing and learning result from the evolution of the *Writing Across the Curriculum* movement of the 1970's into one which currently emphasizes writing as a mode of student learning. The use of *Writing Across the Curriculum* has now evolved into a focus on *Writing to Learn* within disciplines including mathematics (Connolly, 1989; DiBartolo, 2000; Waywood, 1994). Addressing the relationship between learning and writing, Haley-James (1982) stated six elements to encourage learning through writing which include: 1) Writing focuses thought; 2) Writing makes thought available for inspection; 3) Writing allows more complex thought; 4) Writing translates mental images; 5) Writing is multisensory; 6) Writing motivates communication. When students recognize that writing, thinking, and reflecting are interwoven processes, writing encourages learning to occur (Haley-James, 1982).

Joan Countryman a longtime proponent of *Writing to Learn Mathematics* states a connection between knowing mathematics and doing mathematics. As a result of Countryman's approach to the teaching and learning of mathematics, she has uncovered many benefits of *Writing to Learn Mathematics* based on her students' works. She has

determined that writing is a way to help students uncover what they “know” and “do not know”(Countryman, 1992). In addition, writing results in connections between prior knowledge and what is currently being learned. Having students write about these connections and summarize what they know, have learned, and can do provides both the students and the teacher insight into these connections. Writing provides students opportunities to ask questions about mathematics that they otherwise might not have asked. It opens a door to new ideas and new questions. During the process of writing, students are constructing mathematics for themselves rather than waiting for someone else, specifically the teacher, to do it for them. Finally, students are put in situations where writing forces them to reflect on what they know and is a critical step in constructing meaning and making connections (Countryman, 1992). So eloquently stated by Countryman,

We need to create situations where students can be active, creative, and responsive to the physical world. I believe that to learn mathematics, students must construct it for themselves. They can only do that by exploring, justifying, representing, discussing, using, describing, investigating, predicting, in short by being active in the world. Writing is an ideal activity for such processes (p. 2).

The very nature of mathematics requires mathematicians and students to write, but they do so often in a symbolic language. Although those who are practitioners are able to think and express ideas clearly, students of mathematics frequently lack the background to do the same. Students are more successful when they understand the language of the course. Having the ability to engage and construct knowledge as part of the learning process is critical to success in a mathematics course. *Writing to Learn Mathematics* is a way for students to express and communicate thoughts about

mathematical concepts, provides students the opportunity to distance themselves from their problem solving processes, and learn to reflect on these scenarios to create meaning (Connolly, 1989).

Types of Writing in Mathematics

Powell and Lopez (1989) describe writing as a “powerful instrument with which to reflect on experiences, and like mathematics is a major tool for thought” (p. 159). They determined two distinct approaches to *Writing to Learn Mathematics*: product and process-product. In product writing, demonstration of knowledge is shared. Writing about mathematics is the focus not the learner. Alternately, writing is a way of knowing in process-product writing as writing is used to focus first on the learner and then on the mathematics. These approaches have historically been classified as transactional and expressive writing by Britton et al (1975). Product approaches to writing must be considered as transactional writing. Students are required to produce writing that is often algorithmic in nature, topically supplied by the teacher, and impersonal. In contrast, process-product approaches to writing move students through the expressive-transactional continuum. This form of writing demonstrates students’ independent thinking and requires critical reflection on the part of the student (Powell & Lopez, 1989). Powell and Lopez also state process-product writing “is used primarily as a means to learn mathematics and about oneself, not just as a means to measure information acquisition” (p. 160).

Clarke, Waywood, and Stephens (1993) feel that learning mathematics has its foundation in constructing mathematical meaning. It is the role of the mathematics classroom environment to provide experiences which allow students to construct

mathematical meaning. Clarke et al. (1993) state “mathematical meaning requires a language for its internalization within the learner’s cognitive framework and for its articulation in the learner’s interaction with others” (p. 235). Difficulties in mathematics often arise based on issues with mathematical language. Connections between the English language and symbolic mathematical language is lacking for many students. To find clarity in mathematical language, it needs to be about something real to the student (M. Burton, 1992). Showing additional support for the connection between communication and mathematics lies with NCTM’s Communication Standard. Per NCTM the Communication Standard also infers experiences which stimulate learning result when communication is at the heart of the classroom (National Council of Teachers of Mathematics, 2000). Students are required to communicate mathematically and use mathematics to communicate when the construction and sharing of mathematical meaning is elaborated and promotes student reflection (Clarke, et al., 1993). Writing is one mode used to highlight learning in mathematics. With a focus on journal writing intended to help students become active in constructing mathematical knowledge, students were able to reflect on and explore mathematics and in turn heighten metacognitive abilities (Clarke, et al., 1993). For students to acquire and utilize metacognitive skills, Clarke et al. (1993) emphasize that a progression in writing must occur. Students must transition through three modes of writing: Recount, Summary, and Dialogue. As students progress from listing events in the classroom to summarizing work done and topics covered to creating an internal dialogue concerning the mathematics being learned, they are able to construct meaning and make connections. Similarly, Gopen and Smith (1990) state students must see writing as a new mode of thought which requires engagement. “Forcing them to *write* about what they

are doing will in turn force them to *think*, to conceptualize about what they are doing” (p. 4). Students need to move away from simply completing an assignment and work towards understanding and developing conceptual connections (Gopen & Smith, 1990).

Sipka (1992) creates a framework that displays the versatility of writing as a tool to learn mathematics. Sipka’s framework is strongly connected to a broader summary described by Paul Connolly as part of a compilation of works focused on *Writing to Learn* in the mathematics and science arena (Connolly, 1989). Sipka takes elements of Connolly’s summary and creates organization in such a manner as to distinguish in detail the nuances of each approach to writing in the learning of mathematics.

According to Sipka (1992), all writing assignments fall into two categories: informal and formal. Informal writing is focused on the content and the reader is mainly interested in viewing a hardcopy the writer’s thoughts. Substance, rather than structure and mechanics, is the focal point. In contrast, formal writing requires the reader to examine both content and quality of the writing. Multiple revisions may be required along with significant time outside of the classroom to complete the work (Sipka, 1992).

Drawn from Sipka’s work, Figure 3 describes his framework for the variations of types of writing used in mathematics classrooms as a vehicle to improve students’ thinking/learning skills. He describes the use of informal writing, such as in-class writing, to improve students’ understanding by allowing students to take “conceptual ownership”. Students are able to articulate mathematical concepts in their own language. The inclusion of math autobiographies as a course requirement conveys interest in both the individual student’s math histories and is a path to cultivate a positive classroom environment. Informal writing may or may not be graded, but is frequently used for formative assessment and student engagement (Birken, 1989).

Formal writing such as proofs and process papers, as used by Sipka, requires students to revise and reflect. Mathematical structure and analysis over grammatical content should still be the focus in formal writing (Birken, 1989). Within formal writing, students are able to experience writing that is linear and sequential as well as writing which improves students' thinking by revealing mathematical misconceptions, thoughts and comfort level with the content (Sipka, 1992).

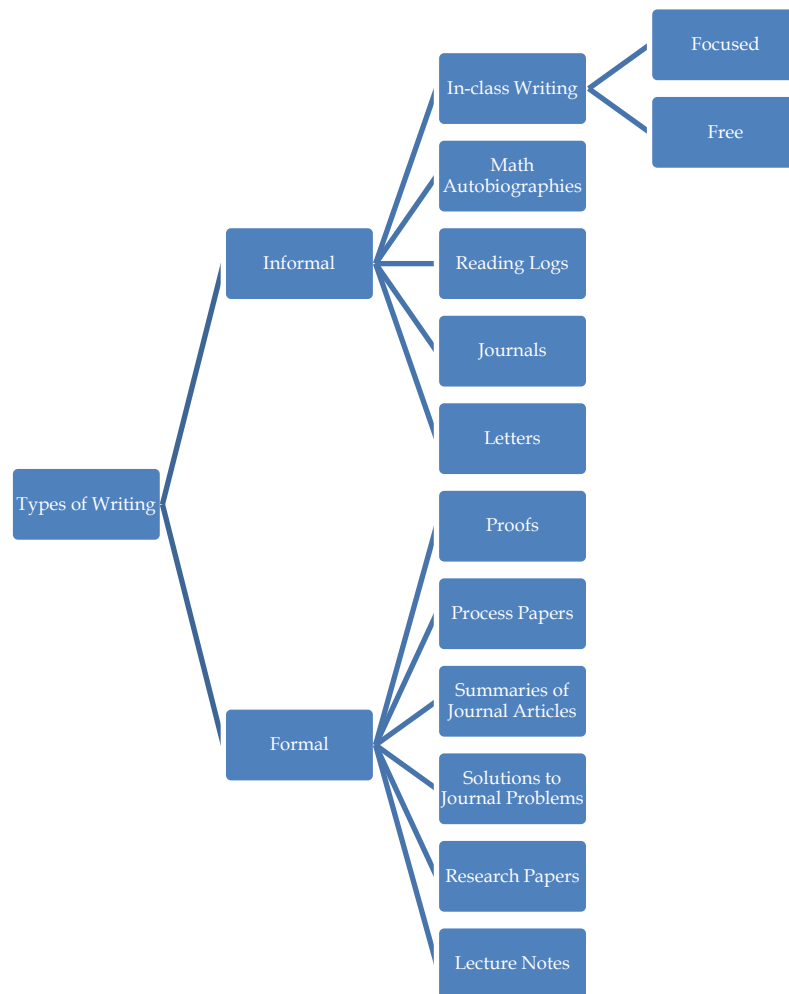


Figure 3. Types of Writing (Sipka, 1992)

Benefits of Writing in Mathematics

While communication of mathematics through writing has been supported and encouraged by NCTM, some insight as to the benefits of its use and its contribution to metacognitive growth also demonstrate the educational value of *Writing to Learn Mathematics*. For students, using journals as a function of *Writing to Learn Mathematics* can ease tension, fear, and discomfort in relation to learning mathematics. For teachers and students, journals can provide insight into students' abilities and stronger interpersonal connections can be established through more frequent interaction based on reading and replying to journal entries (Burkam, 1992). Additional potential benefits as stated by Borasi and Rose (1989) also include benefits to both students and teachers. Benefits for students include therapeutic effects, mathematical content growth, improvement in learning skills, and a changing world view of mathematics. As students record their mathematical processes, they become more self-aware. A written record allows students the opportunity to reflect on their skills, knowledge, and areas to improve. Borasi & Rose (1989) feel asking students to "become introspective of how they do and learn mathematics" is crucial for students' success (p. 356). Benefits for teachers include formative assessment processes to meet individual student needs and improve individual student learning as well as make necessary changes and course improvements based on student needs. Additionally examination and improvement in approaches to teaching and learning based on insights gleaned from students' responses can encourage teachers to reexamine their educational approaches. As such, significant instructional changes which promote interaction and innovation in the classroom are potential results. Benefits for both students and teachers include an improved classroom

climate based on mutual trust and support and more individualized teaching from the dialogue created through the student-teacher exchange of journals (Borasi & Rose, 1989).

One major benefit is the shift from passive learners to active learners (Birken, 1989; Rose, 1989). *Writing to Learn Mathematics* provides an avenue to deeply engage students with the content in a manner not available by simply using exams and quizzes. It can reveal a great deal about students' mathematical misconceptions, allow the teacher to identify where a students' thinking has gone awry, and most importantly generate enthusiasm for learning the subject matter (Birken, 1989). According to Rose (1989) with the incorporation of writing in mathematics students are allowed to grow at their own rate. While using their own experiences and language, writing in the mathematics classroom "facilitates personal engagement in learning; ...keeps a record of individual students' travel through their mathematical experiences; and promotes a caring and cooperative atmosphere through writing interaction" (p. 27).

Ganguli and Henry (1994) performed a detailed examination the literature on the benefits of *Writing to Learn Mathematics* as part of a grant sponsored by the Center for Interdisciplinary Studies of Writing at the University of Minnesota. In examining the literature specific to *Writing to Learn Mathematics* from 1997 to 1990, they netted forty-seven articles. Of these, only four appear to provide empirical evidence to support the benefits of *Writing to Learn Mathematics* with all of the articles dating between 1983 and 1989. From the remaining articles while mainly anecdotal information was offered, the vast majority believe that integrating writing into mathematics courses greatly improved students understanding of mathematics in general. Specifically, *Writing to Learn Mathematics* increased student comprehension, improved communication between students and teachers, allowed teachers better insights into students' learning, and

changed attitudes for the better in both teachers and students toward the teaching and learning of mathematics (Ganguli & Henry, 1994).

Metacognitive Connections

Frequently, metacognition is simply stated as “thinking about thinking”, but according to the work of Flavell (1979) metacognition consists of metacognitive knowledge and metacognitive experiences.

“Metacognition” refers to one’s knowledge concerning one’s own cognitive processes and products or anything related to them...e.g., the learning-relevant properties of information or data...metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data on which they bear, usually in the service of some concrete goal or objective (p. 232).

Metacognitive knowledge refers to the knowledge acquired about the world through cognitive or psychological matters (Flavell, 1979, 1987). Additionally, Flavell divides metacognitive knowledge into three categories: knowledge of person variables, knowledge of task variables, and knowledge of strategy variables. Individual knowledge of one’s learning process and how people learn makes up knowledge of person variables. The nature of the task and the cognitive processing demands of the task are the components for knowledge of task variables. Knowledge of strategy variables encompasses knowledge for both cognitive and metacognitive strategies including appropriate applications of these strategies (Flavell, 1979, 1987). According to Flavell (1987), metacognitive experiences in turn are “conscious experiences that are cognitive and affective. What makes them metacognitive experiences rather than

experiences of another kind is that they had to do with some cognitive endeavor or enterprise, most frequently a current, ongoing one" (p.24). These types of experiences involve feelings of frustration or difficulty when perceiving, comprehending, remembering, or solving, the feeling an intended cognitive goal is just short of being reached or is still very far off, or a sensation in which material seems to be getting easier to understand moment by moment. Flavell (1987), states that one way to improve metacognition is through practice. He infers metacognitive experiences may assist with metacognitive development. One such experience is writing. "Writing also affords practice and experience in metacognition. It allows one to critically inspect one's own thoughts. It also encourages the individual to imagine the thoughts of others" (p. 27).

It is essential to recognize the two separate but inter-related aspects of metacognition: (1) knowledge about cognitive processes and products, and (2) the monitoring and control required in relation to cognitive actions (Flavell, 1987; Pintrich, 2002). Brown (1987) provides an extensive look at the historical roots of metacognition. One of the foundational elements is self-regulation. She states that learners "regulate and refine their own actions" (p. 89) and in doing so utilize a skill that is integral to learning. Self-regulatory functions are critical function for growth and change as learners (Brown, 1987). Additionally according to Garofalo and Lester (1985), metacognitive beliefs though often overlooked, as well as decisions and actions, are vital contributors to success or failure on a wide variety of cognitive tasks. Having sufficient knowledge in addition to having awareness and control of that knowledge determines student success in relation to cognitive performance (Garofalo & Lester, 1985).

Schoenfeld (1987) expanded these two aspects of metacognition into three where he includes knowledge about one's own thought processes, control or self-regulation,

and beliefs and intuitions. His work related to metacognition and mathematics emphasizes students developing skills to make realistic assessments of what they can learn. This requires students to reflect on their thinking and examine the accuracy of their thinking as well as making sure students can determine what they know about a problem prior to attempting a solution. His intent is to develop strategic and reflective learners who can monitor their solving processes and decide what to do, when to do, and how long to persist on a chose path of a solution (Schoenfeld, 1987).

Lucangeli and Cornoldi (1997) provide additional information on metacognition and the context of the learning process. Their focus examines two distinct categories of metacognition, metacognitive knowledge or awareness and executive control over the task. Their study determined mathematical learning requires different levels of metacognitive involvement. Some aspects of mathematics become automated processes over time and require less metacognitive involvement while other tasks such as problem solving demand “complex and flexible thought processes” (p. 123). These authors infer their results suggest the assessment and teaching of metacognitive skills in mathematics courses and conclude that metacognition was a valuable component in predicting mathematical abilities (Lucangeli & Cornoldi, 1997).

This conclusion supports the notion stated by Flavell (1979),

It is at least conceivable that the ideas currently brewing in the area could someday be parlayed into a method teaching children (and adults) to make wise and thoughtful decisions as well as to comprehend and learn better in formal educational settings (p. 910).

Metacognition, Mathematics, and Writing

For students to experience the metacognitive elements of writing per Herrmann (1990), they must first understand that effective writing is “a constructive, problem solving process requiring effort, enthusiasm, perseverance, thinking and strategic reasoning” (p 87). Then it is necessary for students to understand the role of prior knowledge and how to evaluate this knowledge when writing. Meaning students must learn to access relevant information related to what they are composing for inclusion in their written text. Finally, students must be aware of their general thinking ability in relation to writing. This requires students to learn how to strategically approach writing tasks, plan prior to actual writing, maintain their focus on the writing task, and monitor their writing process, progress, and performance (Herrmann, 1990).

Writing to Learn in mathematics provides students the opportunity to show what they know and can do mathematically. The more students reveal to their teachers through writing about their feelings, abilities, beliefs, and misconceptions allows teachers to guide and improve student learning in relation to mathematics as well as build self reflection in relation to learning. Multiple studies demonstrate that students develop a more positive attitude toward mathematics, learn to think about mathematical process and reflect on these processes, utilize appropriate mathematical reasoning and explain their reasoning process, as well as recognize the importance of effectively communicating their knowledge (Borasi & Rose, 1989; Clarke, et al., 1993; Mayer & Hillman, 1996; Miller, 1991; Nahrgang & Petersen, 1986; Powell & Lopez, 1989; Rose, 1992). Using *Writing to Learn Mathematics* provides learners opportunities for mathematical growth and self-awareness that can easily develop metacognitive growth.

As learners progress in mathematics, radical shifts in mathematical conceptual knowledge occur due to significant restructuring of mental models. Metacognition is a pivotal for long term acquisition of these mental models as students struggle make sense of new information while battling existing mental models and beliefs (Carr, 2010). According to Carr (2010), "Given the complexity of changes that need to occur for students to progress in mathematics, more research needs to be done on how reflection can influence conceptual change in mathematics" (p. 192).

CHAPTER 3: METHOD

This chapter highlights the research methodology and procedures used in this study. The purpose of this study was to provide empirical evidence of students' overall academic achievement as well as their mathematic conceptual growth in addition to their metacognitive growth by using *Writing to Learn Mathematics*.

This study focused on the follow research question:

How does *Writing to Learn Mathematics* as an assessment tool in a Trigonometry course relate to overall achievement and self-reflection with respect to learning mathematics?

Specifically,

1. What types of students are enrolled in these two sections of Trigonometry and how are the students in the course similar/ different with respect to background, mathematical ability, and experience with *Writing to Learn Mathematics*?
2. Is there a significant difference in student exam scores for the portion of the course where students experience *Writing to Learn Mathematics* versus the portion of the course where students do not experience *Writing to Learn Mathematics*?
3. What is the nature of students' individual metacognitive functioning and in what ways does this change during the course of this study as students utilize various writing activities which engage students in individual reflective writing as part of the course?

Research Design and Rationale

This study employed a mixed-methods approach using an integrated sequential concurrent design utilizing a within subjects quasi-experimental quantitative component along with a sequential qualitative component. A mixed-methods study utilizes both qualitative and quantitative research methodologies and methods in the research process. According to Creswell and Plano-Clark (2007), “by mixing the datasets the researcher provides a better understanding of the problem than if either dataset had been used alone” (p. 7). As such, multiple forms of evidence are necessary for audiences such as policy makers and practitioners to document and inform research problems.

During the late 1950’s, the foundation was laid for mixed methods research when researchers began to use more than one method in a study. As cited in Creswell and Plano-Clark (2007), in 1959 Campbell and Fiske “advocated for the collection of multiple forms of quantitative data to study the validation of psychological traits” (p. 15). As stated by Hanson et al. (2005), “their work was instrumental in encouraging the use of multiple methods and the collection of multiple forms of data in a single study” (p. 225). From this point on more studies began to utilize multiple forms of data. As a result, a paradigm debate occurred during most of the 1970’s and 1980’s in which some researchers argued qualitative and quantitative methods are incompatible while others adamantly suggested undeniable connections existed between the two traditions (Creswell & Plano Clark, 2007; Hanson, Creswell, Plano Clark, Petska, & Creswell, 2005; Tashakkori & Teddlie, 1998). Although the debate related to paradigms is still present, the foundation is in place along with strong support for mixed methods research design.

With respect to philosophical paradigm and the best foundation for mixed methods research, there are multiple perspectives as well. For this researcher, the

philosophical paradigm best suited for this study is pragmatism. In terms of making connections between pragmatism and mixed methods research, some interpretations from Creswell (2003) include when engaging in mixed methods research both qualitative and quantitative assumptions may be applied, and based on needs and purposes, researchers are able to choose the methods, techniques, and procedures of research which are able to provide the best understanding of the research problem. The ultimate goal of mixed methods research is to draw on the strengths while minimizing the weaknesses of both qualitative and quantitative methods within a single study or across studies (Johnson & Onwuegbuzie, 2004). According to Johnson & Onwuegbuzie (2004) when using insights and procedures from both qualitative and quantitative approaches, researchers are often able to produce superior outcomes.

Mixed methods research focuses on the research question(s) in such a manner that the researcher is given the best chance at answering the research question(s) without being limited to a menu of designs or approaches from traditional qualitative and quantitative research. Thus mixed methods research provides the researcher with the opportunity for multiple approaches to collecting and analyzing data within a theoretical lens that reflects current issues frequently tied to social justice along with educational and political aims (Creswell, 2003). As summarized by Creswell (2003), “for the mixed methods researcher, pragmatism opens the door to multiple methods, different worldviews, and different assumptions, as well as to different forms of data collection and analysis in the mixed methods study” (p. 12). Because this researcher feels that numbers alone do not tell the entire story, when it comes to students’ learning in mathematics or when undertaking any form of research, this researcher will always

collect multiple forms of data which require the use of different strategies, approaches, and methods to produce enhanced results.

Conceptual Framework

This study employed a mixed method approach using a qualitative study design element with emphasis on template analysis and supported with inferential statistics from a cross-over study design. Creswell and Plano-Clark (2007) indicate this research design to be QUAL+QUAN where both methods are used at the same time with equal emphasis for the duration of the study.

Although the term Triangulation has become overused in research design, it is still used for this study. To avoid confusion, Triangulation as defined by Creswell and Plano-Clark (2007) is a single-phase design requiring the researcher to incorporate quantitative and qualitative methods within the same timeframe while maintaining equal weight (Creswell & Plano Clark, 2007). For this study, concurrent and sequential but separate data collection and analysis have been completed as shown below in Figure 4 to assist the researcher in best understanding the research problem. The two data sets, now merged, are discussed and interpreted during the analysis portion of the study. Triangulation, as stated by Creswell and Plano-Clark (2007) “is used when a researcher wants to directly compare and contrast quantitative statistical results with qualitative findings to validate or expand quantitative results with qualitative data” (p. 62).

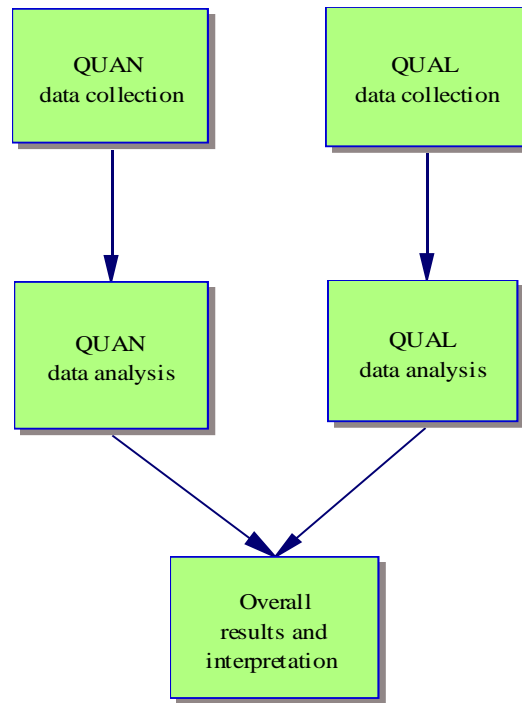


Figure 4. Triangulation Design adapted from Creswell and Plano Clark (2007) p.46

In addition, the theoretical grounding for this study is based on the works of influential individuals in the field of assessment in general and assessment in connection to mathematics education. This framework delineates a reformed view of assessment in which assessment plays an integral role in teaching and learning. According to Graue (1993), instructional assessment must be considered part of the larger assessment system. Connections between assessment and instruction must be strengthened while participation from students and teachers needs to increase. Appropriate criteria for evaluating our assessment strategies and their use must also be developed. All of these pieces contribute to the framework based on the social conditions of schooling which dictate changes in the way we know students (Graue, 1993).

To create a model of classroom assessment that supports teaching and learning while maintaining a social constructivist perspective requires a melding of recent

theories of curriculum, learning, and assessment. Shepard (2000) provides a model adapted from Graue which demonstrates shared principles of curriculum theories, psychological theories, and assessment theory as characterized by an emergent, constructivist paradigm (Shepard, 2000, 2001). Figure 5 lays out the framework utilized for this study. For this framework to be effective, it requires two fundamental changes be made to comply with and support the social constructivist model of teaching and learning.

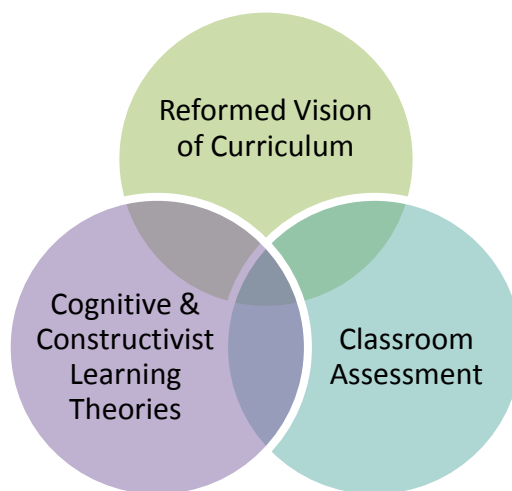


Figure 5. Social Constructivist Framework

First, there must be better representation of fundamental skills in each discipline which requires a change to the form and content of classroom assessments. Second is a change as to how assessment is viewed by teachers and students as well as the way assessment is used in the classroom (Shepard, 2000). Teachers require the ability to assess learning that is based on observations, collections of student work, and students' self evaluations in addition to conventional assessments. A cultural shift for students is also required to focus on learning as a whole rather than learning for the test. Assessments which promote deeper understanding involves collaboration between teachers and students to

assess prior knowledge, uncover misconceptions, and deconstruct areas of confusion (Shepard, 2001).

While keeping the overarching framework in mind, Figure 6 provides detailed elements of the framework that must be incorporated into a model of classroom assessment that supports teaching and learning while operating within the social constructivist perspective. Each of the main principles is broken down to provide the perspectives necessary for learning to occur by an active process of sense making.

Cognitive and Constructivist Learning Theories	Reformed Vision of Curriculum	Classroom Assessment
<ul style="list-style-type: none"> •Intellectual abilities are socially and culturally developed •Learners construct knowledge and understandings within a social context •New learning is shaped by prior knowledge and cultural perspectives •Intelligent thought involves "metacognition" or self-monitoring of learning and thinking •Deep understanding is principled and supports transfer •Cognitive performance depends on dispositions and personal identity 	<ul style="list-style-type: none"> •All students can learn •Challenging subject matter is aimed at higher order thinking and problem solving •Diverse learners are given equal opportunities •Students are socialized into the discourse and practices of academic disciplines •The relationship between learning in and out of school is authentic •Students foster important dispositions and habits of mind •Students enact democratic practices in a caring community 	<ul style="list-style-type: none"> •Challenging tasks elicit higher order thinking •Learning processes as well as learning outcomes are addressed •The assessment process is ongoing and integrated with instruction •Assessments are used formatively in support of student learning •Expectations are visible to students •Students actively evaluate their own work •Assessments are used to evaluate teaching and student learning

Figure 6. Shared Principles of Curriculum Theories, Psychological Theories, and Assessment Theories Characterizing an Emergent Constructivist Paradigm detailed by Shepard (2000, 2001)

This researcher approached the study from the perspective of the reformed vision of curriculum and applied various classroom assessments as described in Figure 6. By incorporating alternative assessments into the mathematics classroom, all students are provided with multiple approaches to learning and have the avenues to demonstrate their learning as diverse learners are given equal opportunity to show their mathematical understanding and growth. Challenging subject matter which requires

higher order thinking can be discussed and dissected in multiple forms to get beyond surface level thinking. Students are fostering important dispositions and behaviors that will apply to their future professions in mathematics, science, and engineering. As for the focus of the classroom assessments, the intent was to elicit higher order thinking which requires students to reflect on what they are learning as well as have students evaluate their own work using writing as a vehicle to do so.

In addition to the conceptual framework developed by Shepard, a conceptual framework for the teaching and learning of mathematics is necessary. Instead of adopting a model for the more general discipline of educational psychology, a narrower definition is required which focuses on the nature of mathematics knowledge and mathematical learning. In terms of epistemology and mathematics research on students' beliefs about the nature and acquisition of knowledge, the problem of knowing has not typically been labeled as either "personal epistemology" or "epistemological beliefs". Rather the literature has used only the construct of beliefs and has focused on how beliefs develop, how they influence engagement in learning and problem solving, and explored how beliefs may change over time (Muis, 2004). The research indicates that much like the field of educational research, there is also no single consistent theoretical framework to work from when examining students' beliefs about mathematics (McLeod, 1992).

Multiple researchers have divided students' beliefs into two types: appropriate and inappropriate. This separation is based upon the relationship between beliefs' influence on learning and learning outcomes (Muis, 2004). As such, beliefs that have a positive correlation between behaviors and learning outcomes such as understanding of mathematical concepts and academic achievement are considered appropriate beliefs

(Schoenfeld, 1988, 1989). Thus appropriate beliefs, also referred to as sophisticated beliefs, are those associated with higher order thinking skills, deeper understanding, and problem solving.

According to Muis (2004), “In the context of mathematics epistemological beliefs, beliefs include perspectives on the nature of mathematics knowledge, justifications of mathematics knowledge, sources of mathematics knowledge, and acquisition of mathematics knowledge” (p. 326). These beliefs provide the “mathematical world view” one may hold (Schoenfeld, 1992) which is the perspective one takes to approach mathematics and mathematical tasks. In addition, beliefs are also described as a critical component of creating meaning and establishing goals which define the contexts of learning mathematics (Cobb, 1986). Students often believe when learning mathematics, memorization of facts and formulas in addition to procedural practice is sufficient (Garofalo, 1989). Another disconcerting belief uncovered by Garofalo is students’ overall view of mathematics and restated in Muis (2004) is that students see mathematics as a “highly fragmented set of rules and procedures rather than a complex, highly interrelated conceptual discipline” (p. 327).

According to the critical review of research conducted by Muis (2004) on students’ beliefs of about mathematics, the majority of the research suggests that students at all levels, including those in undergraduate levels, hold inappropriate beliefs. Students feel the goal of mathematics is to find *the* right answer. Students also believe mathematics knowledge is passively doled out by some authority figure being either the teacher or the textbook author. Students also indicate that mathematics is not learned via logic or reasoning. In addition, students believe that those who can do mathematics were born with an innate ability or the “mathematics gene”. Finally,

students believe they are not capable of constructing mathematics knowledge and solving problems independently (Muis, 2004).

For a change in beliefs to occur, instructional changes which support these changes must be evident. Four conditions are indicated as necessary for conceptual change to transpire. There must be dissatisfaction with old beliefs and intelligibility, plausibility, and fruitfulness of new beliefs (Pintrich, Marx, & Boyle, 1993). An awareness of one's beliefs is also an important catalyst for change. Furthermore, students' beliefs parallel the types of instruction in they are immersed (Muis, 2004). Instructional and assessment designs that support constructivist-orient approaches result in a shift to more appropriate beliefs by students related to mathematics. Muis (2004) indicates that

Constructivist-oriented approaches to teaching focus on establishing mathematics in meaningful and authentic contexts, engage students in collaboration and group activity to construct mathematical knowledge, are process oriented, and provide time for students to learn. These type of instructional designs are associated with beliefs that mathematics is a way of thinking and that mathematical knowledge is interrelated and related to other disciplines and other facets of life, is learned over time with effort, is not innate, and can be constructed individually rather than passively received from the authority-the teacher (p. 363).

Knowing that students' beliefs effect how they learn, NCTM standards suggest that while assessing students' general mathematical knowledge, assessment of students' beliefs about mathematics is an essential component as well. Based on the research

related to how beliefs influence the ways students engage in learning, there appears to be evidence that epistemological beliefs can be a factor in relation to students' learning methods and achievement. This study and the researcher's approach to teaching and learning emphasized an assessment technique that can facilitate a change in beliefs about learning mathematics. Students engaged in *Writing to Learn Mathematics* were asked to express their beliefs about learning mathematics and to reflect on how these beliefs may or may not have changed over the duration of the intervention.

Participants

The participants in this study were students enrolled in two sections of Trigonometry at a community college in Northern Colorado during the spring semester of 2010. These two sections of the course were offered during the same term and both sections were included in this study. The groups had approximately the same mathematical experiential level as students enrolled in Trigonometry must either successfully complete College Algebra, have the appropriate ACT score to place into the course, or have the appropriate ACCUPLACER (institutional mathematics placement exam) score to register for the course. The researcher chose this course as it is a prerequisite for the Calculus sequence and is often a challenging course for many students. This course contains multiple concepts that are foundational for success in the Calculus sequence and often requires students to approach their learning differently than previous courses based on the nature of the material. This course frequently requires students to utilize higher order thinking skills to make connections across concepts within the course. The distribution of students who remained enrolled in the course after the add/drop deadline and also consented to participate in the study were

as follows: 12 students in the morning with section 10 consenting, 12 students in the evening section with all 12 consenting to participate. Initial enrollment prior to the add/drop deadline was higher for each section with approximately 20 students per section, but due to work obligations, family issues, time commitment required for the course, and health issues fewer students than expected completed the course and/or consented to take part in the study. The morning section met on Monday, Wednesday, and Friday while the evening section met Monday and Wednesday.

Intervention

Overall Design

This portion of the study utilized a cross-over design. The intent of a cross-over design is to examine main-effects using **within** subjects differences in which each subject acts as his or her own control while removing between-subjects variation as a source of error (Morgan, Gliner, & Harmon, 2006; Toutenburg, 2002). See Figure 7.

Experimental Group 1(NR):	X	O ₁	X	O _m	~X	O ₃	~X	O _f
Experimental Group 2(NR):	~X	O ₁	~X	O _m	X	O ₃	X	O _f

Figure 7. Design of Study: Cross-Over Design where X represents the group receiving the intervention and ~X the group without the intervention.

Each subject self-selected into a section of the course forcing non-random groups and a quasi-experimental design. Using a random number generator, the intervention order was determined and randomly assigned resulting in the morning section receiving the intervention first. Thus, the morning section of the course was assigned as Group 1

and the evening section as Group 2. Group 1 utilized the intervention, *Writing to Learn Mathematics*, for the first half of the term while Group 2 course requirements excluded these writing assignments for the first half of the term. With the exception of the threaded discussion writing activities and mathematical growth journal entries for the course portfolio as these are the intervention for the study, all other course requirements were identical. In the second experimental timeframe, the role of the groups was reversed. Group 2 received the writing intervention while Group 1 ceased to use *Writing to Learn Mathematics* until the end of the term where a final writing assessment was included for all students from both sections of the course during the same timeframe as the final exam.

Qualitative Design

For the qualitative data obtained during this study, a Basic Interpretive Qualitative study design was used. This study design, according to Merriam (2002), is used when “the researcher is interested in understanding how the participants make meaning of a situation or phenomenon, this meaning is mediated through the researcher as an instrument, the strategy is inductive, and the outcome is descriptive” (p. 6 & 7). Data via interviews, observations, or document analysis are inductively analyzed to uncover “recurring patterns or common themes” that emerge from the data. By framing the study within the current literature, a meaningful and descriptive explanation of the discoveries can be presented and examined (Merriam, 2002).

For this study, students were asked to write about mathematics in various ways. These documents were analyzed using Thematic Analysis. Thematic Analysis requires the researcher to focus on identifiable themes and patterns of experiences (Aronson,

1994). Specifically, Template Analysis was used to analyze the text-based data acquired during this study. Template Analysis is the development of a coding “template” which condenses themes determined as significant within the data set by the researcher into meaningful and useful information (King, 1998). In other words, it allows the researcher to make sense of the data.

First, data must be collected. Then it is necessary to identify all data that relate to some strongly expected themes. Using some *a priori* codes or themes, a subset of the data is examined for initial coding. Next the subset is related back to the research question(s) and revisions to the coding may be necessary based on the outcome of the coding process. This process is the deductive coding portion of Template Analysis. After, or simultaneously with, the initial coding with respect to *a priori* themes, new themes may also be defined as they emerge from the data set. This process is the inductive coding portion of Template Analysis. Using both deductive and inductive coding processes, the coding template is typically revised multiple times. Once the coding template has been finalized, all included documents are now coded using the finalized version of this template. Then interpretation and write-up of the findings can be completed based on the extractions from the data set (King, 1998; School of Health and Human Sciences- University of Huddersfield).

Procedure

In spring semester 2010, Group 1 (Morning) and Group 2 (Evening) began the term with a short survey at the start of the term to provide demographic and background information. The researcher also examined grades from students’ previous course, College Algebra, to examine equivalence of groups as well as ACT and

ACCUPLACER cut scores. It is rare for a student to place directly into Trigonometry as both ACT and ACCUPLACER cut scores are quite high. Both Group 1 and Group 2 then composed a mathematical autobiography. Each student wrote a short essay related to who they are as a mathematics student as well as addressed the students' approach to mathematical thinking and experiences with *Writing to Learn Mathematics*. Themes from these writings were examined to look at experience levels related to *Writing to Learn Mathematics* to further establish equivalence of groups as well establish differences in themes that may appear at the end of the term.

Group 1 then continued to complete various writing assignments until approximately mid-semester. The writing assignments primarily consisted of threaded discussions and journal entries for the course portfolio. The threaded discussions were assigned at regular intervals, approximately every other week, and focused on making connections between course concepts, finding real world applications of trigonometry, as well as study strategies. The first exam was given approximately six weeks into the course prior to the mid-term exam and completed by both groups. Students in both groups then also completed a mid-term exam. During the first half of the course leading up to the mid-term exam, Group 2 completed equivalent coursework with the exception of the writing assignments. At approximately mid-semester in conjunction with the mid-term exam, Group 1 and Group 2 continued to complete equivalent coursework, but the intervention for the groups was reversed. Group 2 then completed the writing assignments as described above while Group 1 no longer performed any required writing. This was the cross-over phase of the study. At the end of the term, both sections of the course completed an end of term essay which asked students to reflect on their growth and achievement using writing in mathematics. Student were to

specifically address their experience during the timeframe when they were asked to use *Writing to Learn Mathematics* and what, if any, differences they notices while using *Writing to Learn Mathematics* in making conceptual connections to the course. A third exam was given mid-way between the mid-term exam and the final exam to both groups as well.

At mid-term and at the end of the term, students in each section of the course took a cumulative content exam using a course portfolio. The mean scores for each student were determined and the two conditions compared using inferential statistics. While students were permitted to use their course portfolios on the mid-term exam and the final exam due to the cumulative nature, portfolios were not permitted on the other two exams in the course, exam one and three. Additionally, the first exam and the third exam were also compared using inferential statistics. SPSS statistical software was used to analyze the quantitative data set collected during the course of this study. A minimum alpha level of 0.05 as recommend for cross-over designs was used for all statistical tests (Toutenburg, 2002). Effect sizes and confidence intervals are also included in the statistical analysis and discussed in Chapter 4. See Figure 8 for additional detail of study.

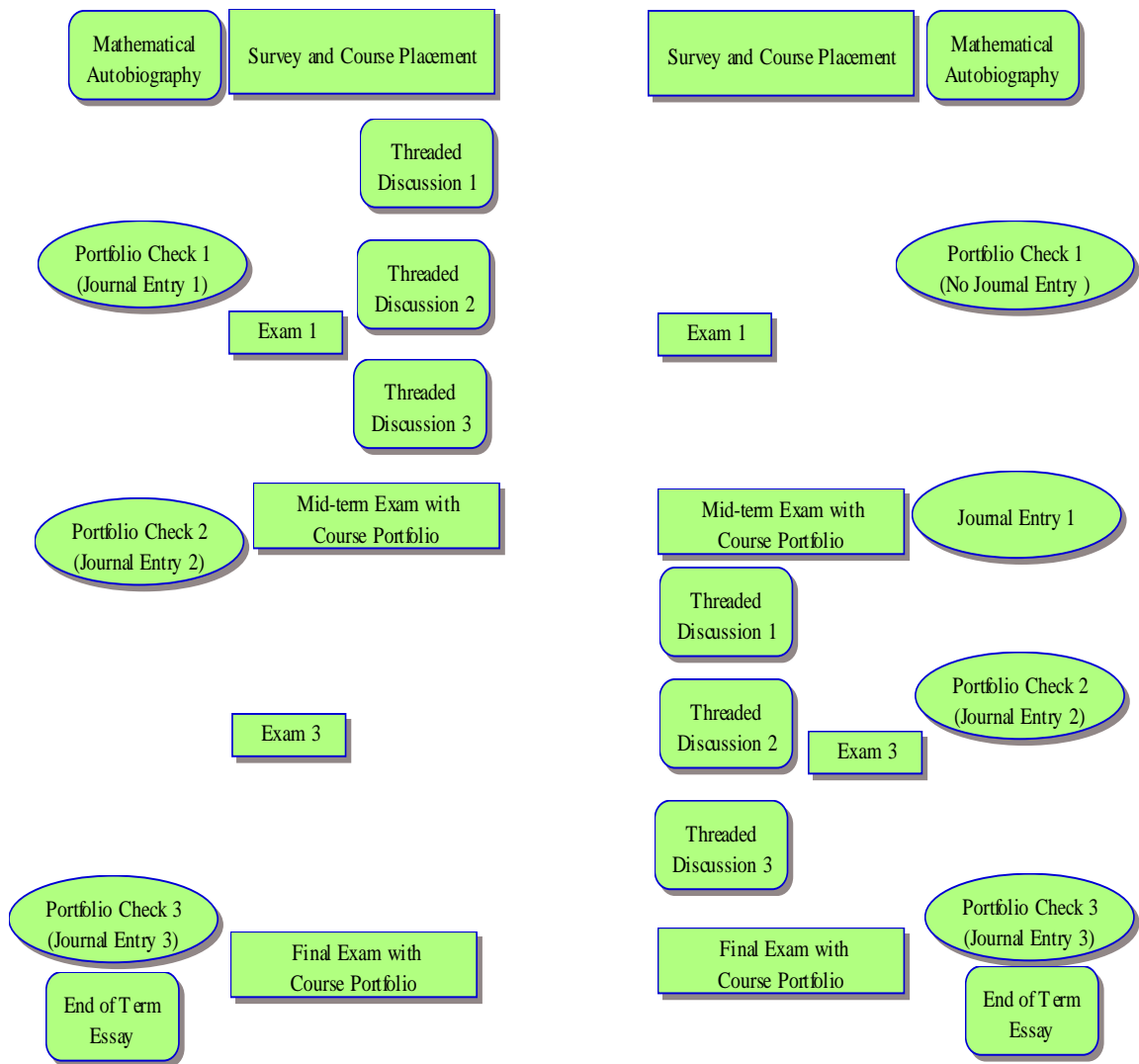


Figure 8. Intervention and Study Design

Quantitative Instruments

The instruments used for this portion of the study include instructor created exams including: exam one, mid-term exam, exam three, and the final exam. Exam one and three, the mid-term exam, and final exam were all piloted prior to the spring of 2010. Multiple revisions were made to all exams based on time allowed, difficulty, use of a course portfolio, and previous students' scores. The exact version of the final exam was used for the 4 semesters previous to this study in which the researcher taught the

course. In addition, a version similar to this version of the final exam was used for the 4 semesters previous to these. The first two terms the researcher taught this course, completely different version of the final exam was used as a course portfolio was not a requirement for successful completion of the course. As such, this researcher feels the evolution of this exam has resulted in a high degree of reliability and validity based on previous students' successes and the revisions made to the exam to reflect appropriate types of questions used throughout the course to encourage deeper reflection on the part of the students. On a side note, final exams are not returned to students. The mid-term exam was piloted in the fall of 2009 and is based off of a combination of the first two exams in the course. Similar versions of the first two exams have been offered multiple times over the last 4 semesters. Revisions to the mid-term were also made based on time allowed, difficulty, and students' success and then incorporated for use in this study. Both the mid-term and final exams are comprehensive in nature, and students are permitted to use the portfolio they have created, based on course guidelines, while taking the exam. Exams one and three are chapter exams which focus only on the specific concepts within a given chapter and required students to apply the skills, necessary formulas, and approaches learned within this chapter as well as reflect on and describe connections across course concepts.

Data Analysis

Quantitative Data Analysis

Statistical analysis was performed on results from the background questionnaire using descriptive statistics. These statistics were utilized to examine information about the two groups with the possibility of making comparisons that arose as a result of the

data collected in the questionnaire. Due to the within subjects design, a paired samples t-test was performed exploring the gain scores of the subjects on their mid-term and final exams and their first and third exams to determine the effects of the intervention *Writing to Learn Mathematics*. In addition, effect sizes were also calculated to determine whether the effect is substantive regardless of the results of the paired sample t-test.

Qualitative Instruments

Qualitative data was collected from excerpts of students' writing. Students were asked to complete an autobiographical essay at the start of the term and a reflective essay at the end of the term as previously mentioned in the quantitative design section. The autobiographical essay was posted in a public forum within the course management system, WebCT, while the reflective essay was submitted in a closed forum via WebCT in which only the instructor had access. In addition, students were to post thoughts on and responses to questions related to course concepts in the threaded discussions in WebCT as well react and respond to other students' posts within the threaded discussion forums in WebCT. An additional source of data came from journal entries for the course portfolio. Three journal entries were required which focused on course activities connected to specific concepts which students found to highly improve or impact their mathematical growth during the course. Finally, all students in both sections wrote an end of term essay addressing their overall growth. This essay required students to discuss writing as a key element of the course and address additional course activities that may have improved their overall conceptual growth, their ability to make connections between concepts as a result of writing or these

activities, and describe any changes students' may have experienced as a learner which were influenced by the reflective nature of these writing assessments.

Qualitative Data Analysis

Based on pilot data from previous sections of the course and prior to the study, some *a priori* codes were determined for each of the writing elements. Using this information, a template for each of the writing elements was loosely developed to use in coding of the autobiographies, journal entries, threaded discussions, and end of term essays. Using these templates and coding of the students' writing include in the sample, revisions to the templates were made and further coding required as additional themes emerged. Word count and analysis of level of writing was also examined as part of the data analysis.

CHAPTER 4: RESULTS

The purpose of this study was to provide empirical evidence of students' overall academic achievement as well as their mathematic conceptual growth in addition to their metacognitive growth by using *Writing to Learn Mathematics*. This chapter presents the results of the three research questions posed in chapter three. The findings for the research questions are both quantitative and qualitative in nature. The results to these questions are presented in a sequential manner, quantitative then qualitative, although the data were actually collected simultaneously.

Description of the Sample

The study took place at a community college in Northeastern Colorado. The college serves approximately 5500 students per semester and has over 160 programs of study. There are both two- year guaranteed transfer programs and Career and Technical Certificate programs offered at the institution. The general student population is made up 56% females and 44% males with 24% of the entire student population being Latino/Hispanic students. Of the students enrolled at this college 45% require financial aid assistance. In addition, 38% are full-time students and 62% are part-time students. Student ages can vary greatly in the classroom and range from 14 to 70. The percentages for enrollment in 2009 are as follows: 21 and Under at 45%, 22 – 29 at 27%, 30 – 49 at 22%, and finally 50 and Over at 6% ("Aims Community College", 2010).

For this study, the sample included 22 students. Ten students were enrolled in the morning section of the course and 12 students were enrolled in the evening section

of the course. The morning class was 60% male and 40% female while the evening class was 83% male and 17% female. The morning class had 40% part-time students and 60% full-time students enrolled while the evening class had 67% part-time students and 33% full-time students enrolled. Of the students enrolled in the morning class, 70% were Caucasian, 20% Latino/Hispanic, and 10% checked the “Other” category. For the evening class, 75% were Caucasian, 10% Latino/Hispanic, 10% African American, and 10% Asian.

Table 1. Demographic Information as Percentages for the entire College, Morning Section, and Evening Section

	College	AM	PM
Male	56	60	83
Female	44	40	17
Part-time	62	40	67
Full-time	38	60	33
Caucasian	66.2	70	70
Latino/Hispanic	22.4	20	10
African American	1.5	0	10
Asian American	1.8	0	10
Other/Unknown	8.1	10	0
Under 21	45	70	66
22-29	27	10	17
30-49	22	20	17
50 and Above	6	0	0

In examining pre-requisites for the 22 students who took part in the study, no student had an ACCUPLACER score and only one student used his or her ACT score to place into the course. Three students earned transfer credit as they completed the course at another institution of higher learning while the remaining eighteen students satisfied their pre-requisite by successfully completing College Algebra at this institution. Based on a review of the course grades for the morning and evening sections, further analysis on this variable was not required. The course grades were approximately equivalent for the two sections based on the number of A's, B's, and C's for each section.

Of the students enrolled in both sections of the course all but two were enrolled due to requirements for their choice of major. With a focus on Engineering, Computer Science, Architecture, Mathematics/Mathematics Education, or Science these students were required to take this course as a pre-requisite for Calculus I or were specifically required to take Trigonometry for their major. The two students enrolled in the course who had not yet decided what to choose as a major indicated a high personal interest in the content of the course and a positive association with mathematics in general.

Quantitative Results

To answer the quantitative research questions, the statistical package SPSS (Statistical Package for the Social Sciences) 18.0 was used. The results to each research question are listed under separate headings.

Research Question One

What types of students were enrolled in these two sections of Trigonometry and how were the students in the course similar/ different with respect to background, mathematical ability, and experience with *Writing to Learn Mathematics*?

The first research question addressed what types of students were enrolled in these two sections of Trigonometry and how the students in the course were similar/different with respect to background, mathematical ability, and experience with *Writing to Learn Mathematics*. Because the sections of the course used for this study were not offered in identical time formats and the students enrolled self-selected into the morning or evening sections of the course based on meeting the pre-requisite and convenience for the student, it was necessary to determine if the two groups in the study were indeed equivalent.

Chi-Square Tests were used to determine equivalence of groups for 2X2 pairings on multiple dichotomous and nominal variables. For the pairings involving group and gender, group and student type, group and ethnicity, group and English 121, group and pre-requisite, group and work status, and group and why the student was taking the course, there were no significant differences. Thus the morning and evening groups can be considered equivalent on all previous categories. In addition, writing in mathematics from previous courses was also examined to lay a baseline as to the level of experience and familiarity the students had with writing in mathematics. To determine if the two groups were any different with respect to writing in mathematics, group and journal entries, group and learning logs, group and threaded discussions, group and exam essay questions, group and conceptual essays, and group and the narration of mathematical steps were also compared. Of these categories, only one was statistically significant. The morning group had more experience with essay questions on exams than did the evening group (). Based on the overall results for writing in mathematics, the groups were also approximately equivalent.

In summary, the two groups were essentially equivalent as there were no significant differences with respect to background, mathematical ability, and experience with writing in mathematics. The only difference in the groups occurred as a subset of the writing in mathematics category, *Writing to Learn Mathematics*, with the morning group having more experience with essay questions on exams than the evening group. Based on the indicated results, the two groups of students enrolled in the morning and evening sections of this Trigonometry course were considered essentially equivalent for the purpose of this study.

Research Question Two

Was there a significant difference in student exam scores for the portion of the course where students experience *Writing to Learn Mathematics* versus the portion of the course where students do not experience *Writing to Learn Mathematics*?

The second research question examined if there was a difference in student exam scores for the portion of the course where students experienced *Writing to Learn Mathematics* versus the portion of the course where students did not experience *Writing to Learn Mathematics*. To address this question, sets of exam scores were analyzed to compare writing and non-writing portions of the course. One set of exams, the mid-term and final exams, allowed the use of a course portfolio during the exam. A second set of exams, the first and third exams, did not allow the use of a course portfolio. Based on the cross-over design, non-writing and writing pairs were compared for all exams in the course and another comparison was examined for the set of exams in which a portfolio was not permitted. As a result, the study design created groups in

which each student was his or her own control requiring a paired sample *t*-test as recommended by Morgan et al. (2006).

The cross-over design is detailed below to provide a framework for the initial data mining where *X* was the group which received the intervention *Writing to Learn Mathematics* and $\sim X$ was the group without the intervention. The observations represent each exam given in the course. Exams one and three did not allow students to use their course portfolio while the midterm and the final exams allowed the students to use their course portfolio.

AM Group (NR):	<i>X</i>	O_1	<i>X</i>	O_m	$\sim X$	O_3	$\sim X$	O_f
PM Group 2(NR):	$\sim X$	O_1	$\sim X$	O_m	<i>X</i>	O_3	<i>X</i>	O_f

Figure 9. Design of Study: Cross-Over Design where *X* represents the group receiving the intervention and $\sim X$ the group without the intervention.

To set up the necessary pairs for the cross-over design, the data first needed to be sorted into writing and non-writing sets. Because students were their own control, each students' set of writing and non-writing scores were aligned. All exam scores were not out of 100, so in creating the writing and non-writing pairs, the mean scores for exams were necessary. It is important to note students were able to get a score above 100% or 1 as each exam contained one or two bonus questions. This allowed a student to score 105 or 109 on an exam giving a total more than 100 points on a 100 point exam.

First an overall set containing writing and non-writing pairing was established. This set included 2 exams which were averaged, exam 1 plus the midterm and exam 3 plus the final. Then exam 1 and exam 3 averages as writing and non-writing pairings were created and compared. Table 2 summarizes the process used in creating the

overall writing scores for each student who was a participant in the study. Student 1 was in the morning section and received the intervention during the first half of the semester, so exam 1 and the midterm were used in creating the student's overall writing score. These two exams were added together and then divided by the total number of points to determine the average score on the two exams completed during the portion of the semester in which the student experienced the intervention *Writing to Learn Mathematics*. Student 11 was in the evening section and experienced the intervention the second half of the semester so exam 3 and the final exam were averaged to get this student's overall writing score.

Table 2. Overall Writing Scores for the Crossover Design

Writing	E1 (am) / E3 (pm)	Midterm (am) / Final (pm)	Writing Score
Student 1	97	51	0.8457
Student 2	82	49	0.7486
Student 3	106	72	1.0171
Student 4	90	48	0.7886
Student 5	113	79	1.0971
Student 6	76	54	0.7429
Student 7	57	44	0.5771
Student 8	96	37	0.7600
Student 9	84	39	0.7029
Student 10	111	73	1.0514
Student 11	91	116	0.7667
Student 12	98	119	0.8037
Student 13	87	147	0.8667
Student 14	90	143	0.8630
Student 15	67	140	0.7667
Student 16	93	154	0.9148
Student 17	95	136	0.8556
Student 18	97	150	0.9148
Student 19	96	157	0.9370
Student 20	91	158	0.9222
Student 21	71	92	0.6037
Student 22	84	74	0.5852

Table 3 summarizes the process used in creating the overall non-writing scores for each student who was a participant in the study. The scores that were averaged came from the two exams completed during the portion of the semester in which the student did not experience the intervention *Writing to Learn Mathematics*. Because Student 1 was in the morning section and received the intervention during the first half of the semester, the non-writing score came from exam 3 and the final exam. Student 11 was in the evening section and experienced the intervention the second half of the semester so exam 1 and the midterm were averaged to get this student's overall non-writing score.

Table 3. Overall Non-Writing Scores for the Cross-Over Design

Non- Writing	E3 (am) / E1 (pm)	Final (am) / Midterm (pm)	Overall Non-Writing Score
Student 1	95	140	0.8704
Student 2	68	114	0.6741
Student 3	100	156	0.9481
Student 4	76	141	0.8037
Student 5	106	167	1.0111
Student 6	92	143	0.8704
Student 7	38	90	0.4741
Student 8	85	130	0.7963
Student 9	61	111	0.6370
Student 10	104	158	0.9704
Student 11	77	41	0.6743
Student 12	70	58	0.7314
Student 13	100	61	0.9200
Student 14	101	69	0.9714
Student 15	102	52	0.8800
Student 16	108	71	1.0229
Student 17	99	60	0.9086
Student 18	97	67	0.9371
Student 19	94	76	0.9714
Student 20	93	60	0.8742
Student 21	73	22	0.5429
Student 22	77	28	0.6000

Once the writing versus non-writing pairs were established, a paired samples *t*-test was then performed comparing the writing and non-writing pairs. The results of the paired samples *t*-test indicated there was no statistical significance with $t(21) = 0.117, p = 0.908$. Because these some of these exams allowed the use of a course portfolio, the researcher wanted to see if comparing the exams which did not allow the course portfolio alone showed any significant differences. So an additional comparison was made within the writing and non-writing pairs to further examine achievement tied to exams scores for the first and third exams as these exams. The results of the paired sample *t*-test indicated once again no statistical significance with $t(21) = 1.317, p = 0.202$ with an effect size of $d = 0.28$. The data for paired comparisons used in the *t*-tests is summarized in Table 4.

Table 5 summarizes the results of the quantitative analysis detailing no significant difference between the exam scores pairs overall as well as for exam 1 and exam 3 pairs with respect to the writing and non-writing portions of the course. According to Morgan et al. (2004), “statistical significance is not the same as practical significance or importance” (p. 89). As such, examination of effect sizes can provide additional information about the strength of the relationship between the independent and dependent variables (Cohen, 1988). Interpreting the strength of the relationship based on guidelines developed by Cohen (1988), the effect size calculated showed a small effect in the exam 1 and 3 score pairs for the writing versus non-writing where a course portfolio was not allowed on the exam.

Table 4. Writing and Non-Writing Pairs for Paired Comparisons

	Overall Writing Score	Overall Non- Writing Score	E1 (am) / E3 (pm) Writing Score (no portfolio)	E1 (am) / E3 (pm) Non-Writing (no portfolio)
Student 1	0.8457	0.8704	0.97	0.95
Student 2	0.7486	0.6741	0.82	0.68
Student 3	1.0171	0.9481	1.06	1.00
Student 4	0.7886	0.8037	0.90	0.76
Student 5	1.0971	1.0111	1.13	1.06
Student 6	0.7429	0.8704	0.76	0.92
Student 7	0.5771	0.4741	0.57	0.38
Student 8	0.7600	0.7963	0.96	0.85
Student 9	0.7029	0.6370	0.84	0.61
Student 10	1.0514	0.9704	1.11	1.04
Student 11	0.7667	0.6743	0.91	0.77
Student 12	0.8037	0.7314	0.98	0.7
Student 13	0.8667	0.9200	0.87	1.00
Student 14	0.8630	0.9714	0.90	1.01
Student 15	0.7667	0.8800	0.67	1.02
Student 16	0.9148	1.0229	0.93	1.08
Student 17	0.8556	0.9086	0.95	0.99
Student 18	0.9148	0.9371	0.97	0.97
Student 19	0.9370	0.9714	0.96	0.94
Student 20	0.9222	0.8742	0.91	0.93
Student 21	0.6037	0.5429	0.71	0.73
Student 22	0.5852	0.6000	0.84	0.77

Table 5. Comparison of Writing to Non-writing Scores (N = 22).

Variable	<i>Mean</i>	<i>SD</i>	<i>t</i>	<i>df</i>	<i>p</i>	<i>d</i>
Pair 1- Exams Overall			0.117	21	0.908	0.02
Writing Score	0.824	0.14				
Non Writing Score	0.822	0.16				
Pair 1- Exams 1 & 3			1.317	21	0.202	0.28
Writing Score 1&3	0.852	0.16				
Non Writing Score 1&3	0.810	0.19				

To determine if additional analysis should be conducted on the quantitative data set, comparisons of means between the morning and evening sections on each set of exams was also made. Because the means of each set of exams scores did not show obvious differences between the am and pm scores, it could be determined that additional analysis would not change the outcome of the quantitative results. See Table 6.

Table 6. Mean Scores for Exams

	Exam 1	Exam 3	Midterm	Final
Am	0.8160	0.8250	0.6947	0.7941
Pm	0.7983	0.8833	0.7077	0.7775

Quantitative Summary

The intent of comparing writing and non-writing scores on exams was to determine if there was a significant difference in student exam scores for the portion of the course where students experienced *Writing to Learn Mathematics* versus the portion of the course where students do not experience *Writing to Learn Mathematics*. In short, to determine if writing had an effect on students' performance on exams. The results for the quantitative portion of the study taken independently do not appear to have an effect on students' overall achievement as the results of the paired samples *t*-test determined no statistical significance between exam scores for the writing and non-writing portions of the course.

While the results from the quantitative portion of the study were not statistically significant, effect sizes indicated a small effect and suggest a need for additional information. This value could result purely due to chance or could indicate a relationship between the intervention and achievement which may be explained in a

more meaningful way by the study's participants. Statistical significance does not give information about the strength of a relationship or size of the outcome. Effect size however demonstrates the strength of the relationship between the independent variable and the dependent variable (Morgan, Leech, Gloeckner, & Barrett, 2004). Although the effect size showed a small effect, in terms of practical significance, this type of intervention requires changes in approaches to learning and teaching which can be done in a very cost effective manner rather than making a high cost curricular revisions. Although the results for the paired samples *t*-tests were not statistically significant, the opportunity to examine students' responses provided additional insight as to the effects of *Writing to Learn* in a mathematics course and lack of significance in the quantitative portion of the study. Further exploration of the data using qualitative approaches gave the researcher additional information about the overall effectiveness of the intervention *Writing to Learn in Mathematics* which could not be determined via quantitative methods.

Qualitative Results

Paralleling quantitative data collection, this study also involved the collection and interpretation of qualitative data utilizing an approach referred to as "template analysis". Template analysis creates a framework in which the researcher has a guide to analyze qualitative responses from study participants. Template analysis is a widely accepted form of coding and is frequently referred to as "thematic coding" (King, 1998). According to King (1998), "the essence of the approach is that the researcher produces a list of codes (a template) representing themes in their textual data" (p. 118). The researcher starts with *a priori* codes which are then modified as additional data is

extracted. The initial codes are then modify and expanded from the existing general themes to more specific and detailed themes. This process requires the researcher to make inferences and conclusions about particular themes requiring both inductive and deductive coding.

Research Question Three

What is the nature of students' individual metacognitive functioning and in what ways does this change during the course of this study as students utilize various writing activities which engage students in individual reflective writing as part of the course? To address the third research question, an initial template was developed from questions asked of students on their first writing excerpt for the course. All students completed a Learning Biography the first week of the course which addressed: who they are as a student, feelings they have toward mathematics in general, their strengths as a mathematics student, goals for this course, long term educational goals, and why the student felt he/she would be successful the course. Students were specifically asked not to focus on the grade they wanted to earn, but rather their thoughts as to "who they are" as a learner. The initial template consisted of these six constructs (Figure 9) and all study participants' responses were coded using the initial template. Data extraction initially demonstrated a fairly superficial level of reflection. The majority of the Learning Biographies did not address all of the questions asked, lack specific detail, and lacked substantive self-examination. All student comments are given under a pseudonym to ensure anonymity.

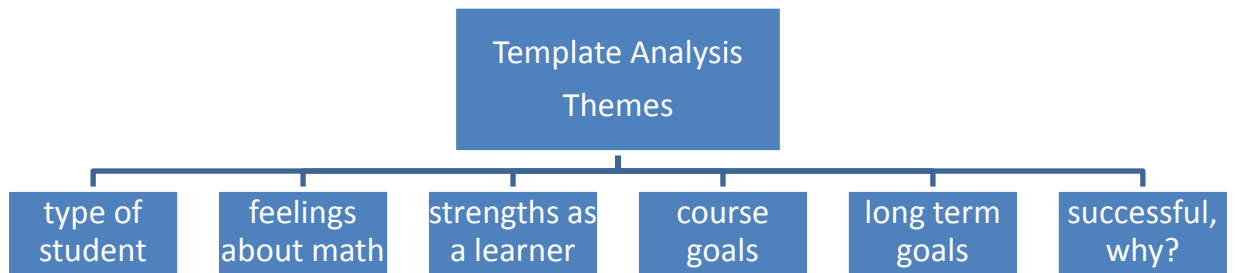


Figure 10. Initial Template

Within the course goals construct, the brevity of students' comments, the emphasis placed on course grades, and the superficial level of self-examination, demonstrate a low level of metacognitive functioning related to students self-concept as to who they are as a learner.

Alex stated,

"My goal for this class is to get a B or better. Also to learn all that will apply to an engineering job which I plan to do at the completion of my degree. I want to get as much knowledge as I need to a job in the engineering field well."

Randy commented,

"I want to have an A or B in this course when all is over because I know I can do it. I have taken pre calculus and I hope I can still remember some of the concepts that I learned them to make this class a little simpler."

Jack said,

"Of course I would like to receive a good grade, but I have greater goals for this class. As I mentioned before, I enjoy learning new material. Unfortunately, I couldn't get into my desired math class at my high school this semester so I decided that I would take this Trigonometry class in its place. One goal is to challenge myself to learn more in order to be successful in the career I would like to pursue."

Within the type of student construct, the comments also lack detailed self-examination and did not provide much insight into the individuals as learners.

As stated by Evelyn,

"I enjoy learning and being challenged in my education. I have a wide range of interests, finding almost any topic enjoyable. This, coupled with a large work ethic, has allowed me to succeed in my educational career so far."

Cole said,

"As a learner I am very inquisitive. I enjoying learning new things, and if I don't get it at first I work at it until I do. My Grandpa always told me that a wise person tries to learn something new every day, and the person who thinks they know it all is an idiot."

Christine wrote,

"I was a hands-on learner. If I learn at my own pace, I found that the material sticks with me."

After completion of the coding from students' writing excerpts from their Learning Biographies with the assistance of NVivo, version 8, additional excerpts from other writings in the course were coded also using the initial template. Because the *a priori* codes did not fit all the additional qualitative data sources, revisions to the initial template were made from general categorical themes to more contextually specific themes. Writings were focused on connections between and within specific course concepts along with writings which provided students prompts that probed students to delve deeper into their approaches to learning. The addition of these excerpts to current qualitative data source file required revision and expansion of the initial template. With a focus on mathematical connections or an emphasis on self-evaluation as a learning tool, the follow comments demonstrate how students' writing was beginning to change. Thus requiring changes to the initial template.

Chakimbu stated,

"From these new realizations, I was able to understand the other four trigonometric function and their graphs. Soon, my paper plate became more of a quick referencing tool than a visual aid. I hope that I will be able to use my unit circle as I move on to a higher level math."

As described by Randy,

"I now realize how much trigonometry is in our world because of writing the connections we all can make through the concepts of this course. Trigonometry is everywhere, and by doing the research to find out these things it makes learning trig a little easier because we actually know we can use these concepts in the real world."

Dan wrote,

"I do see the connection between writing and math just like anything you learn, the more you think about what you need to work on the more effort you will put into actually doing it."

Based on overlapping text within the data set from additional writings which include one threaded discussion, three mathematical growth journal entries, and the end of term essay, the template was revised to include the following themes: changes as a learner, connections and writing, feelings about math, reflections and writing, and value of writing.

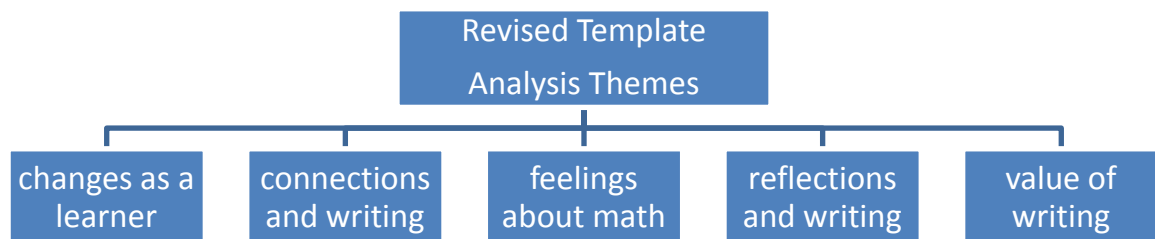


Figure 11. Revised Template

Within each of these five new constructs, additional themes were extracted allowing for another level of coding uncovering changes in students' levels of reflection as a result of using *Writing to Learn Mathematics*. Substantive versus artificial or surface

level changes emerged within the changes as a learner construct. The connections and writing construct uncovered multiple ways in which students were able to find links between mathematics and writing. Students made conceptual connections, found a deeper understanding about mathematical concepts due to writing about them, and were able to see connections related to writing and their future professions or writing and real world scenarios. The feelings about math construct demonstrated a strong feelings either of like or dislike of the course material and mathematics in general with very few students having mixed feelings. Reflection and writing focused on one concept which was foundational to the course, the Unit Circle. The Unit Circle permeates almost every unit of Trigonometry, and is therefore a fundamental element worthy of reflection to make conceptual connections. The connections made by the students through their writing showed either a deeper level of reflection as a result of multiple connections demonstrated within their writing throughout the course or a surface level understanding demonstrated by their writing in which the students presented only minimal connections between the concepts in the course.

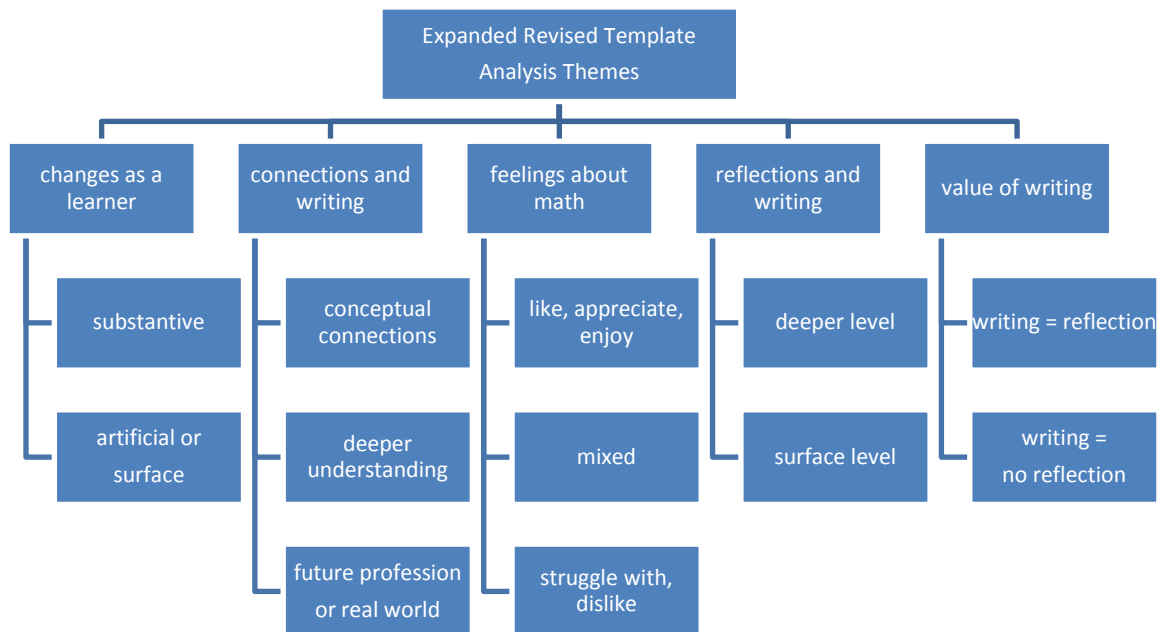


Figure 12. Expanded Revised Template

A critical aspect for this portion of the study was to determine if students found value in writing about the connections they made in the course as well as determine if these students saw writing as an avenue which encouraged them to reflect on what they had learned. Students stated either the various approaches of *Writing to Learn Mathematics* encouraged them to reflect on the course in ways they had not done so previously which they deemed valuable or students saw little to no value in writing. The overall results for the inductive coding using the expanded revised template are described in Tables 7 and 8. Table 7 examines constructs indirectly tied to students' metacognitive changes. The writing excerpts coded within these constructs did not provide sufficient detail and substance to determine any form of effect and were therefore not analyzed in more detail. Table 8 examines constructs directly tied to students' metacognitive changes

Table 7. Number of References for Revised Constructs Indirectly Tied to Metacognition

	Conceptual Connection	Deeper Understanding	Future Profession/ Real World	Like, Appreciate, Enjoy Math	Mixed Feelings	Struggle with, Dislike Math
Morning	0	2	2	7	1	0
Evening	1	5	9	9	5	2
Male	1	7	9	12	5	1
Female	0	0	2	4	1	1

Table 8. Number of References for Revised Constructs Directly Tied to Metacognition

	Substantive Changes	Artificial or Surface Changes	Unit Circle Deep Reflection	Unit Circle Surface Reflection	Writing = Reflection	Writing ≠ Reflection
Morning	6	2	7	7	7	1
Evening	8	4	12	3	10	3
Male	10	4	14	8	13	3
Female	4	2	5	2	4	1

which included numerous references to changes as a learner, reflections and writing, and value of writing. These constructs allowed the researcher to examine students' thoughts and reactions as they experienced writing in a mathematics course and how they may have changed as a result.

To demonstrate the nature of students' individual metacognitive functioning and the ways in which it may have changed during the course of this study, addressing research question three, further examination of students' quotes from the constructs of changes as a learner, reflections and writing, and value of writing were necessary to highlight distinguishable differences and insights amongst the participants in the study. These three constructs focused on the nature of students' individual metacognitive functioning and allowed the researcher to examine how students' individual metacognitive functioning changed during the course of the study.

Within the changes as a learner construct, it was clear when students stated experiences that represented substantive changes or did not seem to experience any changes as a result of the intervention *Writing to Learn Mathematics*. Students' quotes detail the changes they experienced and demonstrate how some achieved a new level of sophistication as a learner or the students' quotes make vague references to superficial changes while providing next to no details about their learning experiences.

Substantive changes are described below in students' own words.

As detailed by Chuck,

"To me I have changed as a learner in the aspect of having to write about connections in math. In College Algebra we never did that. We just learned the material and went on. With Trigonometry we had to step back and reflect on what we learned and apply it to life. This has changed how I learn math. When I learn something new, I have to step back and say 'Does what I learned make sense? Do I have any questions?'" "

Sally commented,

"This semester has definitely helped challenged me and my flaws as a student shone through brightly. On top of trigonometry, I took two rather difficult biology courses and felt a little stretched thin over all of the material. I learned that, in order to fully grasp all three, I needed to make them active parts of my life. Taking a new approach to a mathematics course taught me a bunch of new methods of studying a subject. The most effective method of studying I developed through, is teaching others, regardless their level of participation. Whether I am rambling on to my roommates, friends, parents or coworkers, it is always very helpful for me to explain what I am learning to people. It is much more helpful when I am asked to explain further or provide example because it makes me find new ways to communicate the material other than just robotically reciting it. I'm hoping this new found study habit will help me in math classes down the road since it has certainly proved its usefulness through trigonometry."

Salvador wrote,

"This trig class was a challenge but one that I enjoyed taking. I learned many new things about myself. I think on a new level. Different techniques of teaching, like projects and discussions, helped us experience what tools work with us and are useful. I monitor my learning in a simple way. Instead of writing down my progress or things like that I just think back to how I was as a learner back then and compare it to how I am now. If nothing has changed then I know that I need to work harder. As everyone knows a successful learner is not one that knows a lot or is good at everything but one that can learn from their errors and improve their defects."

Artificial changes were evidenced by students' lack of introspection as well as the brevity of their comments.

Daniel stated,

"I did change more last semester compared to this time as a learner, but I still changed; I really worked on learning the terms and paying more attention to the subject than writing down the notes."

Ellen wrote,

"I never used to read the book before class, but I did this semester and helped me a little bit."

Tim stated,

"As a learner I don't think I have changed very much, I may have learned some patience to see things through and I have also learned some skills in communicating with other people when I am working in groups. I don't think my approach to learning math has really changed very much in total. I work problems until I understand how they work."

Within the reflection and writing construct, students were asked to examine conceptual connections tied to the Unit Circle. The morning class wrote about connections earlier in the term than the evening class, so they were not able to examine elements from the majority of the course as they reflected on connections. However, it could easily be determined regardless of the time of the intervention *Writing to Learn Mathematics* if students were reflecting on what they were learning and making deep connections between concepts related to the Unit Circle as a foundational element of the course as the course progressed or if students were fixated on surface level connections. Students' quotes demonstrate multiple and consistent connections pulling together various facets of the course which utilized the Unit Circle or the quotes focus on elements of the course connected the Unit Circle in a superficial disjointed fashion.

Students who demonstrated multiple and consistent connections described specific connections in a detailed manner which provide insight as to the depth of their understanding.

Evelyn wrote,

"Over the past few weeks of trigonometry, the Unit Circle has transitioned from a paper plate to an applicable tool. When this semester began, I had only heard mention of radians and quite frankly, they made absolutely no sense. Therefore, when we placed the exciting little stickers on our paper plates and labeled triangle points with things such as π and $\frac{\pi}{2}$ — I was completely bewildered. Then we were instructed to use the concept of radian location in order to find the values of the six trigonometric functions, and the light turned on. As I worked through problems such as $\sin(\frac{\pi}{6})$ — and found the value of $\frac{1}{2}$ —, I realized the purpose of my Unit Circle. The Unit Circle contains everything necessary for finding the solutions to these types of problems: the degree, the radian measure, and the location coordinates. It also provides a visual of the relationship among the three types of basic angles, π , $\frac{\pi}{2}$, and $\frac{\pi}{4}$. The continuation of the work with the Unit Circle has led to the discovery of more and more patterns and a development in my understanding of trigonometry's base. As a result of a little bit of colorful paper, stickers, and memorization, my grasp on this aspect of trigonometry has increased tremendously."

Roy commented,

"The main connection that I have made with the unit circle is the relationships to the circle equation . With these relationships I have found it easier to solve for a trigonometric equation and triangles that are larger or smaller. Knowing that all of the trigonometric functions have a definite value with relation to a radius of one, this can be used as multipliers for larger or smaller triangles with specific angle measures. This has definitely helped me in solving and connecting the proportions of triangles with relation to the X and Y axis. This connection to the relationships has also helped in understanding the trigonometric graphs when they are manipulated by the factors that change the shape and size of the curves."

Kip stated,

"Again, a hands-on-learning and also working with peers has helped me learn how it all fits together. The pieces unveil themselves very nicely while doing activities. In my opinion more classes need to have these group projects during class time to give students a different look at what they are doing. From a different perspective I think that making connections in math can take on a whole new meaning. The graphing portion of the projects section of my portfolio has really helped me make those necessary connections to understand the concepts. It's more than any lecture could do for that type of understanding."

Kip B. commented,

"The unit circle has followed me everywhere I go, and I am still in astonishment of how it is still applicable through all these chapters. When we first talked about the unit circle, I thought it was just something that would only be used for a certain one or two things. I also thought that I knew the circle well enough, but when the first unit circle test came around, I was not as familiar with it as I had thought. I got really angry at myself and was determined to do better on the next unit circle quiz. I did do better, but I still messed up by switching some values around. I would say that these tests helped me to get to know the Unit Circle better because they spurred me on to do better. Going over all the connections that the circle had with what we were doing was very instrumental in my understanding of trigonometry and how it all goes together. I was really amazed at how the circle could be use for graphing wave-like data, represent complex numbers, and do plotting in a polar-coordinate system. I still find it crazy that all these topics rely on and are based from a circle with points that correspond with triangle measures. In the end, our constant going over the unit circle and its applications helped me get a grasp on where trigonometry really comes from."

Judy wrote,

"The other reason why I love it (the Unit Circle project) is that we put it together with our hands. They say that "doing" is the best way to learn and I would consider this doing. We cut and pasted and put together the unit circle with our own hands. We labeled it with our own hands and I even trimmed it so that it would fit into a page protector in my portfolio! Manual exercises like that engage a different part of the brain. I

know it helped me feel connected to it. Having both the physical memory and the visual memory of the unit circle is a great combination to getting its information into our long term memory. We need to have this information in our long term memory because the unit circle is connected to so many other aspects of Trigonometry. It is the foundation of more complicated concepts like parametric equations. I really enjoyed the progression of the class and how we started with the unit circle and just kept building on it. Because I have the strong foundation of knowing the unit circle, I believe I am more easily able to learn the concepts that have been built upon it!"

Students with only surface level connections focused on memorization of the Unit Circle, a single concept related to the Unit Circle, or made vague references to conceptual connections rather than stating the actual connections uncovered by building and using the Unit Circle throughout the course.

Chuck stated,

"I have used the unit circle numerous times in my homework and I am still working to memorize all the points on it. By the end of the semester I hope to have the unit circle fully memorized and have full comprehension of its applications."

Randy commented,

"I would like to talk about the Unit Circle in this journal. This has probably been the best activity that we have done in class for me. I was really worried coming into this class knowing that we would be working with the Unit Circle because I didn't really know it like I do now. When we drew it on the Unit Circle and labeled it with everything it put a stamp of that image into my memory. I still have not been able to memorize every bit of it but if I can get the first three triangles labeled with everything then I can put the rest down by looking at the first quadrant triangles because they are the same in each quadrant, but with different radian measures and different signs in front of them."

Christine stated,

"The Unit circle has been a big help in connecting the degrees and radians. And has shown me how a triangle can be formed from the six trigonometric functions such as sine, cosine, and tangent."

Within the value of writing construct and based on students' comments, the researcher was able to determine if students saw any value in writing as it related to their ability to reflect on what they had learned between class sessions and over the

course of the term. The intent of the study was to use writing as an avenue to encourage students to reflect on connections across course concepts at a deeper level and to help students learn the value of self-reflection when it comes to their learning. Thus revealing the nature of students' individual metacognitive functioning and the ways in which it may have changed during the course of this study.

Sally wrote,

"Writing essays in a math class was definitely something new to me but I think it was effective for various reasons. Writing out what was and what was not effective for me caused me to have a level of self reflection that I had never really considered in other math courses. Because of the essays, I was encouraged to pinpoint what was helping me significantly like my revelation about talking through concepts with others."

Kip B. stated,

"I agree that writing in mathematics helps ground the basics and proves what you really know in trig. I personally know that it proved that I really didn't know as much as I thought I did, but that is a good thing because now I know what to fix with myself. It is one thing to do something that makes sense in your head or to repeat some steps someone gave you, but to actually be able to quantify the data and put it down on paper is a whole different thing. This requires an innate understanding of whatever you are trying to write about in order to put it in a coherent and understandable way."

Judy commented,

"I totally agree that writing required me to reflect on what I really know and understand. Outside of not knowing the correct vocabulary, if I couldn't explain a step or process, then that told me I didn't understand it and needed to review. I guess it's kind of like "the devils in the details."

Jack stated that,

"Writing to reflect on what I have learned has shown me how to really appreciate what I have been learning. It has helped me to see how beneficial everything I have learned because I reflect on everything and it forces me to take a second look at it all."

Alex said,

"Yes, I suppose writing and explaining in your own words does make you look back and think about how much you really know on the subject. Also by doing this process it may help to learn a concept because you are forced to think longer and harder about the concept and see other connections to the concept."

Not all of the students who were involved in the study found value in the intervention. Four the study participants saw little to no value in writing and did not feel that writing in mathematics encouraged any form of self-reflection nor did it encourage connections across course concepts. Most of their responses did not provide detail as to why and overall their comments were quite brief. It can be determined they viewed the intervention as a course requirement to be met rather than an opportunity to expand and enhance their approaches to learning.

Tim stated,

"While it is obvious that needing to write about things will increase your reflection about them, I do not think that it was helpful to me to write about uses for trigonometry because I already do this in my head."

Otis wrote,

"I can see how writing out the steps are another form of trying to get the mind to grasp the concept. The journal entries that were required in this class is one that required some writing. I have mixed feelings about the entries, because I can see how it can be useful for students to think about it in a different form other than just the math way. For me, I think it was more of a distraction."

Roy commented,

"The writing in the class was not as reflective or useful in learning Trigonometry better."

Nina stated,

"There may be a connection between writing and math, but as of right now, I do not think it is very helpful for me. It confuses me a little."

Qualitative Summary

With the addition of a threaded discussion, journal entries, and the end of term essay the initial template used to code students' writing proved to be too narrowly focused when the secondary level of coding was compiled in conjunction with the

learning biography composed at the start of the term. Revising the template allowed for more detailed coding and uncovered even more specific themes within the revised template. To address the third and final research question of the study, data from students' writings coded with the expanded revised template emphasized changes as learner based writing in the course, mathematical connections demonstrated through writing in the course, and value placed on writing as a mode of learning and its function in promoting self-reflection. Based on the frequency and insights detailed within student comments, *Writing to Learn Mathematics* appeared to have a profound effect on students as learners and demonstrated both changes and growth in metacognitive functioning as a direct result.

CHAPTER 5: DISCUSSION

The intent of this study was to explore an intervention, *Writing to Learn Mathematics*, within a college level mathematics course. The purpose was to determine the effect such an intervention may have on academic achievement and metacognitive changes in undergraduate students who were enrolled in a Trigonometry course at a community college in northern Colorado. This chapter discusses the results of the three research questions posed in chapter three, draws conclusions based on the results of the study described in chapter four, and makes recommendations for future research. Using a mixed methods approach provided a combination of methods which added breadth and depth to the analysis that may have not been otherwise visible (Erzberger & Kelle, 2003). One concern in this study is the results from the quantitative phase did not agree with the outcome evidenced by the qualitative data collection and analysis. Fortunately, a triangulation design was utilized because: (1) it allowed a researcher to directly compare and contrast quantitative statistical results with qualitative findings and (2) it brought together the differing strengths of the two methods (Creswell & Plano Clark, 2007). The outcome of the study based on this design produced conflicting yet compelling results.

Quantitative Synopsise

In the initial stages of the study design, it was necessary to determine if the two course sections were approximately equivalent. Pre-testing is common to set a baseline for comparison, but this researcher chose not to use a pre-test based on previous

experiences with pre-testing. Students frequently score low on a pre-test and this can either deter students from the course or initially undermine their confidence at the start of the course. As such, a background questionnaire was used to establish an equivalence of groups. Chi-Square Tests were used to determine equivalence of groups involving multiple pairings for various groups of which there were no significant differences. In addition, writing in mathematics from previous courses was also examined to lay a baseline as to the level of experience and familiarity the students had with writing in mathematics, the intervention *Writing to Learn Mathematics*. Of these categories, only one proved to be statistically significant where the morning group had more experience with essay questions on exams than did the evening group. Based on the overall results of the background questionnaire and specifically examining the portion of the questionnaire emphasizing *Writing to Learn Mathematics*, the questionnaire allowed the researcher to determine the groups were approximately equivalent for the purpose of the study without deterring students from the course or undermining their confidence.

To examine the effects of *Writing to Learn Mathematics* on achievement, the study attempted to address if there was a difference in student exam scores for the portion of the course where students experience *Writing to Learn Mathematics* versus the portion of the course where students did not experience *Writing to Learn Mathematics*. For the comparison of writing versus non-writing pairs a paired samples *t*-test was then performed. The results of the paired samples *t*-tests indicated there were no significance differences in the various exam scores compared. One explanation for the lack of significance in the tests is the small sample size. Another is that students were able to use a course portfolio containing terminology, formulas, course projects, corrected

exams, journal entries, and threaded discussions. These additional resources may have removed the potential for differences because students had access to multiple resources and did not have to recall extensive amounts of course information. In addition, each exam offered bonus questions which allowed students the opportunity to score higher than 100%. While it may have improved the outcomes of study results to remove these types of questions from the exams, students' learning and overall course performance was the researcher's primary concern. Because the researcher was also the instructor for the course, providing multiple opportunities for students to demonstrate their mastery of the course concepts took precedence over data collection and analysis. Implementing the study in the least invasive manner to the students, may have also increased threats to external validity. As such, the use of course exams as a measurement may not been the best choice as these exams appear not to be a sensitive enough tool to detect changes in student performance based on the writing intervention. There may be an effect that could have been measured, but the course exams appear not to be sensitive enough to determine any result.

In conclusion, the lack of significance does not imply the intervention had no effect. The effect sizes calculated did indicate a small effect and suggested a need for additional data collection or the examination of an alternate form of data to determine the overall effect of the intervention *Writing to Learn Mathematics*.

Qualitative Synopsise

To examine the effects of *Writing to Learn Mathematics* from another perspective, students utilized various writing activities which were to engage students in individual reflective writing as part of the course. The intent was to explore the nature of students'

individual metacognitive functioning and in what ways it may have changed during the course of this study. The first level of coding focused on general categorical coding using a Learning Biography all students completed the first week of the course. As the semester progressed the inclusion of additional student work, required revisions to the initial template to include more specific levels that directly tied writings to conceptual connections and development, thoughts about changes students made as learners from the beginning to end of the course, and what value they saw if any in using writing to enhance self-reflection. With the new levels of coding, it allowed for a more detailed and in depth analysis of all students' writing included in the course.

The process of coding with template analysis uncovered that many students did make significant changes to their approach to learning, and they were able to make deep and meaningful conceptual connections. It also was apparent that writing in mathematics and about mathematics encouraged students to reflect on what they were learning, and allowed them to make more meaningful connections about the content and themselves as learners. Within the changes as a learner construct, 14 of the 22 students stated they experienced substantive changes as a result of the intervention *Writing to Learn Mathematics* and their comments demonstrate how some achieved a new level of sophistication as a learner. Within the reflection and writing construct, students examined conceptual connections tied to the Unit Circle. Of the students' quotes 19 of 29 coded excerpts demonstrated multiple and consistent connections pulling together various facets of the course which utilized the Unit Circle. Within the value of writing construct and again based on students' comments, the researcher determined 17 of 22 students saw any value in writing as it related to their ability to reflect on what they had learned between class sessions and over the course of the term. The intent of the study

was to use writing as an avenue to encourage students to reflect on connections across course concepts at a deeper level and to help students learn the value of self-reflection when it comes to their learning.

In conclusion, this study revealed the nature of students' individual metacognitive functioning at the start of the term and demonstrated powerful and compelling changes which occurred during the course of this study as a result of the intervention *Writing to Learn Mathematics*.

Integration of Quantitative and Qualitative Results

To complete the triangulation design of the study, integration of the results from the quantitative and qualitative portions of the study is needed. A triangulation design is frequently used to validate or expand quantitative findings with qualitative results or is used to investigate two different viewpoints which might provide a broader more representative picture of the phenomena being investigated when the viewpoints are brought together (Erzberger & Kelle, 2003). According to Ezberger and Kelle (2003), one of three outcomes results when integrating quantitative and qualitative methods. The results converge leading to the same conclusion, the results may be complementary and supplement each other, or the results may be divergent and appear to be contradictory. In this study, there was not convergence. As stated by Teddlie and Tashakkori (2008), integration of findings does not necessarily require convergence. Inconsistencies between results based on different methodological approaches to data collection may provide forms of information that otherwise might be overlooked, and may even present new theoretical perspectives on the events being explored. They affirm the integration of results does not require consistency (Teddlie & Tashakkori, 2008). While the results of the study may appear

to be contradictory, according to Nevo & Nevo (2009), they are in fact conflicting. There is an important distinction between conflicting and contradictory results as contradictions are not logically possible inferring that “No proposition can be both true and false” (p. 110). They also attest that “conflicts are very much possible...they occur in all levels of reality—the natural, the social, and the psychological” (p.110). Conflicts thus are not the same as contradictions. If there are no obvious methodological issues, then it is reasonable to infer the data sets under study unveil distinguishable aspects of the events being investigated and provide a heightened and complete view of reality (Nevo & Nevo, 2009).

Even though there were conflicting results between the data sets, in an attempt to reconcile and approach these results in a meaningful way, the study as a whole must be considered. A key consideration is that while the sample size may be small and contributed to the lack of significance in the quantitative portion of the study, the small effect size indicated the result could be due to the intervention, *Writing to Learn Mathematics*, and not simple due to chance. With the inclusion of qualitative methods in the study, additional information as to the way the students actually perceived the effects of the intervention was available. In examining the change in depth of students’ comments within the references as demonstrated by students’ growth over time and number of references, the intervention *Writing to Learn Mathematics* had a powerful impact on students’ learning. Students detail in their own words ways in which *Writing to Learn Mathematics* provided them with opportunities for self-reflection and metacognitive growth that would not have otherwise been visible. The total numbers of references for the three main constructs, changes as a learner, reflections and writing, and value and writing, which are connected to *Writing to Learn Mathematics* are provided in Table 9.

Table 9. Total References for Research Question Three

Themes	Total References	Morning	Evening
Changes as a Learner	20	8	12
Substantive Changes	14	6	8
Surface level Changes	6	2	4
Reflections and Writing	29	14	15
Deep Reflection	19	7	12
Surface Reflection	10	7	3
Value and Writing	21	8	13
Writing = Reflection	17	7	10
Writing = No Reflection	4	1	3

The vast majority of students involved in the study stated in more than one construct writing in the course had a positive effect on who they are as a learner. One can also infer *Writing to Learn Mathematics* also improved their overall achievement in the course as a result.

Evelyn wrote,

"I do feel that writing to learn mathematics required me to reflect on what I really knew, understood, and could do with respect to trigonometry. The ability to explain a mathematical idea to someone in words required an in-depth understanding of the process itself. If I did not understand what I was learning, then I could not explain the process to someone else. When working on the group project, I had to explain my struggles and help others with theirs in order to succeed. This form of explanation allowed me to gain a deeper understanding and wider approach to mathematics. The various techniques of writing, such as discussions, rationales, self-reflections, definitions, and growth journals required an awareness of my progress as well as an understanding of the material itself. The written communication of concepts forced me to realize the process and basics of the concept, while the self-reflection aspects caused me to focus on what I had mastered as well as what needed more work. In this way, I had to collaborate with others to gain an understanding and push myself to succeed overall."

Judy also commented,

"As far as how I monitor my learning, "then and now", I may have stepped through a threshold on that topic. In the past, I only looked as far as my test score to judge how well I had learned a subject. Although this is accurate to a point, I'm starting to think

that there's a deeper level of understanding that can't always be demonstrated on a test. Now, an essay on a math test would give someone the opportunity to truly explain a process or how they themselves understand something to work. Not that I enjoy writing required essays on tests, but I do see how the process of writing something out reveals understanding of the inner workings of the process. I do like writing in a journal, and it's kind of like that, but with a mathematical twist!"

The quotes from students indicate they realized learning is more than just a score on an exam. They were able to look past the score and determine if they truly understood the concepts by recognizing they can not only "do" the math but "explain it" by "making meaningful connections".

In addition, the results of this study are consistent with finding of a meta-analysis focused on *Writing to Learn*. The meta-analysis included 48 school-based *Writing to Learn* interventions from a search of the literature dating from 1926 to 1999. This meta-analysis found that writing can have a small positive impact on conventional measures of academic achievement resulting in an effect size of $d = 0.26$. Also determined in the meta-analysis which support the results of this researcher's findings were two factors that resulted in enhanced effects of the intervention *Writing to Learn* (Bangert-Drowns, et al., 2004). The first was the use of metacognitive prompts. Metacognitive prompts which asked students to "reflect on their current knowledge, confusions, and learning process proved particularly effective" (p. 50). The second was the length of the intervention. Larger effect sizes in the unweighted analysis were associated with studies that took place over a longer period of time. For writing to have a positive influence on the learning process, it is reasonable to expect "the influence will be cumulative overtime" (p. 51).

Significance of Research

First, it is important to recall the purpose of assessment with respect to learners is essentially two-fold. Assessment is to evaluate student achievement and to provide support and feedback related to students' achievement. Because assessment is an integral part of instruction, instructional goals must be considered when designing meaningful assessment tasks. The promotion of in-depth learning requires students to think about what they are learning. Integrating knowledge into current schema within the learners' mind requires performance in increasingly challenging environments. Learners must think about the connectivity of learning the tasks and not focus on isolated skills and facts. The performance of meaningful complex tasks such as *Writing to Learn Mathematics* ensures students think about the connectivity of learning and how they, as individuals, approach their learning. Meaningful learning is seen as intrinsically motivating and leads to long term mastery (Herman, et al., 1992).

This study suggests alternative assessments in higher education which place an emphasis on assessment for learning promote the type of metacognitive activities needed for long term mastery. *Writing to Learn Mathematics* is such an assessment. Writing is a form of discovery learning that actively engages students and forces students to uncover what they really know about what they are trying to learn (Connolly, 1989; Zinsser, 1988). When student write about mathematics they are using inner speech to translate the subject into a context which makes sense to them. In this study the vast majority of students were able to uncover their misconceptions, learn to think deeply about mathematical concepts, and find ways to make sense out of what they were learning all by using writing in mathematics. The quote below details an

example of how one student was able to use inner speech as mode of learning which resulted from his experiences using *Writing to Learn Mathematics*.

Kip B relays,

At the beginning of the semester, I was extremely excited when I found that Aims had an evening course of trigonometry. Math has always been an interest of mine and for me to have the opportunity to take it at a college level was an extreme blessing. When I walked into the classroom, however, my excitement turned to panic. Although I had taken a college-level math class before, the thought of what I was to learn quickly lowered my confidence. I feel that at the beginning of the course this discouragement showed, for I did not think I was learning and comprehending all of the information that was given to me. In my eyes I felt that if I was to be learning, my attentiveness to the small details, participate more in class discussions, and my retention of each lesson were to be much higher than what I originally perceived it. As time progressed, I began to "loosen up" and participate more in the discussions held in the class; moreover, because of this participation, I feel as though my other expectations for me in the course also began to fall into place. Soon, that excitement that consumed my body was back again. I found myself looking ahead in the book and counting down the days until we reached a section that went over a trigonometric concept that interested me. For each new concept I learned, I picked up a corresponding skill. After completing each project, I found myself using techniques that I subconsciously learned while doing these projects. An example of this is the verification and solving project. During this project we were to write down the steps to the verification of a trigonometric or the solving of a trigonometric expression as though we were explaining how to do it. I started to notice soon after the projects due date that I was speaking to myself whenever I was doing a math problem.

This process is fundamental to learning and doing mathematics as students are allowed to reflect, organize, model, and represent their thinking through writing (Meier & Rishel, 1998). When students recognize the interwoven elements of writing, thinking, and reflecting, students are able to construct mathematics for themselves because they are forced to reflect on what they do not know or understand creating a level of self awareness as a learner that encourages continued growth in students' metacognitive abilities (Clarke, et al., 1993; Countryman, 1992; Gopen & Smith, 1990; Powell & Lopez, 1989).

It is without question the best learning environments result when there are productive interactions between students and teachers. We must create classrooms in

which students use assessment as a path to success and a process for improvement.

Students need to view ongoing course assessment as a way to take ownership of their learning as they ultimately decide if they are smart enough to meet the course standards. They decide if they will succeed or fail, how much effort to put in to meet the standard, and if meeting the standards is worth the required effort. If students are to become responsible for their learning, teachers need to involve students in various classroom assessment techniques, require students to keep records of their work, and encourage communication during the learning. All students need to believe they can succeed if they keep trying. Engaging students in continuous self-assessment over time helps them to believe that success is within reach if they continue to try to attain it (Stiggins, 2004).

As described by Randy,

In the beginning I was very nervous about how well I was going to do in this course. I see now through discipline, hard work, and going to bed at a decent time has really helped me be a better student. No matter what course that I take if I go into each of them with the attitude I have towards math then I can achieve greatness. It is only a matter of will, and by finishing this course I can actually see that if you put in the hard work then great things will happen in due time. I really have to give credit to you Shelly. I really like the courses you teach, and I appreciate all of the things you have done to help me succeed in this class. I am very confident going into calculus because I know that I can do it as long as I apply what I know and always go and ask for help when I need it.

Implications for Practice

This study has implications for mathematics educators, professional development coordinators, and administrators in higher education. Educators must remember their primary role is to help students learn. Learning centered scenarios which require students to take ownership of their learning by actively engaging students with the course material and requiring students to reflect on what they are learning places the learning front and center. Mathematical tasks are centered on reasoning

abilities, can involve in depth problem solving strategies, and often required students to differentiate between appropriate approaches and connections required to make sense of these mathematical tasks (Brown, 1987). While certain skills become automatic, the strategic attitude and metacognitive abilities required in planning strategies and linking concepts are greatly improved through metacognitive exercises like *Writing to Learn* in mathematics. As such, the assessment of and teaching of metacognitive skills should have significant role in instructional practices (Flavell, 1987; Lucangeli & Cornoldi, 1997; Schoenfeld, 1987).

Writing to Learn in mathematics has been explored to some degree in mathematics education research. Shield and Galbraith (1998) discuss the need for further research as many forms of writing in mathematics have been examined and there is much anecdotal evidence but a need for more empirical evidence. This study provides mathematics educators with some additional data to support the use of writing as tool for learning and assessing. The results also give students' positive perceptions of the value of writing in a mathematics course. As such, this study indicates that mathematics educators should include writing as an essential element for assessing students learning.

To support educators with this endeavor, professional development coordinators need to refocus their energy on long term sustainable professional development scenarios which promote deep learning which occurs as a result of metacognitive activities. Learning centered classrooms which place an emphasis on alternative assessments, formative assessments, and active learning to engage students in their learning and encourage metacognition is a way to move students toward deeper learning. In turn, administrators need to support educators as they explore these

approaches. Making the transition to learning centered classrooms takes time and support as all endeavors are not successful. We often learn as much from our failures as our successes. The opportunity to try something new without penalty for the attempt shows faculty that administrators support their endeavors and efforts to make changes which improve student learning. Finally, funding should be provided to support professional development opportunities which encourage learning centered approaches.

Limitations of Research

Connections between writing and learning have been supported in many subject areas that naturally lend themselves to this type of intervention, but more evidence is needed to support the intervention, *Writing to Learn* in mathematics, in higher education. Change occurs slowly at this level and frequently requires quantitative data to support such a change. One critical limitation of this study is due to the small sample size. This made it challenging to provide more detailed quantitative evidence for the research questions posed. The size of the institution and the number of students in need of Trigonometry only allows for a limited number of sections to be offered in a single term. Another limitation is the researcher was also the instructor of record for the course sections involved in the study. This, along with the small sample size, led to the cross-over design for the study. Because the researcher felt it would be too much of a challenge to control any carryover effect due to her beliefs about learning and teaching, the researcher did not use a treatment-control design. An additional limitation was that only one institution of higher learning was used in the study. Inclusion of another institution could have provided a larger sample, but may have also introduced variability between learning environments and across instructors for the course sections.

Because the small sample size is of concern. I feel I should address it in more detail. It was somewhat of a surprise to me that the final number of participants for the study ended up so low. At the start of the semester, the numbers in each section of the course were a somewhat larger. In the morning section, two students, a brother and sister taking the course together, dropped the course prior to the add/drop date. Through some of the initial course assignments, these two students indicated they felt the writing was an extra burden and may drop the course. Another student decided to audit the course due to opening a small business and was not sure how much time would be available to spend on the course. This student wanted to review the content prior to Calculus I and that was the reason for initially enrolling in the course. Because an audit does not result in a grade, this student gradually disappeared from the course. Of the students who completed the course, only two students chose not to participate in the study. Both of these students were high school students and did not return the parental consent form.

In the evening section of the course, three students dropped prior to the add/drop date. All three of the students attended either the first or the second class meeting. From my previous experiences teaching night courses, students have a very limited amount of time to spend outside of class studying and working with other students. Because these students did not stay in the course, most likely they felt the time commitment required to be successful was too much to fit their current schedule. Another student completed half of the course but had to withdraw due an opportunity at work. He was being promoted to a night supervisor and was expected to be there every evening. This conflicted with the time the course was offered. He felt the pay

raise would greatly benefit his family, so he chose the promotion over finishing the course.

Finally, much to my surprise and his, one student in the evening section in his mid thirties experienced a heart attack during the middle of the term. While he completed the course and participated in the study, he did not have the same experience as his classmates. He missed approximately 4 weeks of classes and with much effort on his part and mine we were able to bring him back up to speed to finish the class. Because he was not in class and did not take part in all of the classroom activities, it was difficult for him to make the same types of deep connections and reflect on these experiences as he did not take part in the same way as the rest of the students.

Suggestions for Further Research

While the present study provided a detailed examination of students' perceptions of writing in mathematics and how it affected them as a learner, there is clearly more research needed in this area. More evidence is needed to convince mathematics educators to utilize writing as a way to transform student thinking about mathematics concepts and to foster growth in their students' metacognitive abilities. Based on the value of writing revealed for learning mathematics in this study, I will continue to incorporate and experiment with *Writing to Learn* as an avenue for alternative assessment in the mathematics classroom. As a follow-up to the present study, I will also continue to examine the role of writing as a tool for assessment in the mathematics classroom and hope to include the additional elements of the course portfolio not included in this study in a future study.

Multiple studies which examine the effects of *Writing to Learn* on students' perceptions of writing in mathematics and the changes they experience as learners could naturally follow this study. While this study focused a few specific forms of writing in mathematics, there are other forms of writing in mathematics that could also be explored. However, there is still a need to repeat the present study in other institutions of higher learning within the state and across the nation. In addition to repeating the study, longitudinal data would also be valuable to show how students exposed to writing in mathematics progressed and how it may have affected students' learning. Specifically, longitudinal data could provide long term results for students who persist with writing in mathematics when they are not required to do so as part of a course. Students who persist with writing in mathematics independently would indicate they found value in the intervention and found a way to incorporate this approach to approach to learning in enhance what they are learning about mathematics and themselves as learners.

Finally, in addition to looking at students' perceptions, qualitative interviews on mathematics educators who utilize writing as an assessment tool would likely yield a wealth of information tied to integrating writing successfully into mathematics courses. This data would not only result in a useful archive of resources, but provide a core of knowledge to share with future mathematics educators.

Final Thoughts

A typical teacher spends about one-quarter to one-third of their professional life on assessment related activities. Without proper training teachers may develop poor habits and inaccurate assessments for measuring student success. This means the evidence used to inform what takes place day-to-day may frequently be invalid.

Students suffer the consequences of these incorrect conclusions and counterproductive actions which affect their learning. As all teachers need to know and understand the techniques and principles of sound assessment (Stiggins, 2004), we must better prepare pre-service teachers and assist those currently in the field on the vast array of assessments for learning.

This has been a powerful journey for me. I rediscovered how important it is to put myself in the position of my students. In doing so, I have determined that my role is to help students become the best learner they can, and it is essential for me to assess students in a variety of forms to highlight their strengths and to expose the areas where they can improve. *Writing to Learn Mathematics* has helped me to do so and not only encouraged my students to reflect on where they are as a learner, but who they want to become as a learner. I hope to continue to share what I have learned through my experiences with other educators to inspire them to try something new when it comes to assessment for learning in mathematics. The process of doing this study, and the pilot projects that preceded it, have helped me continue to grow as an educator. I have chosen to walk the path of a life-long learner and can only hope by sharing my journey I encourage my fellow educators to do the same.

REFERENCES

- Aims Community College. (2010). Retrieved August 14, 2010, from <http://www.aims.edu/about/ire/facts.php>
- American College Testing Program. Retrieved October 25, 2009, from <http://www.act.org/news/data/09/pdf/output/NationalOverview.pdf>
- Angelo, T. A. (1999). Doing assessment as if learning matters most. *AAHE Bulletin*, 51(9), 3-6.
- Angelo, T. A., & Cross, K. P. (1993). *Classroom assessment techniques: A handbook for college teachers* (2nd ed.). San Francisco, CA: Jossey-Bass.
- Aronson, J. (1994). A pragmatic view of thematic analysis. *The Qualitative Report*
Retrieved August 4, 2009, from <http://www.nova.edu/ssss/QR/BackIssues/QR2-1/aronson.html>
- Artzt, A. F., & Armour-Thomas, E. (1992). Development of a cognitive-metacognitive framework for protocol analysis of mathematical problem solving in small groups. *Cognition and Instruction*, 9(2), 137-175.
- Association of American Colleges. (1985). *Integrity in the college curriculum: A report to the academic community*. Washington, D.C.: Association of American Colleges.
- Asturias, H. (1992). Using students' portfolios to assess mathematical understanding. *Mathematics Teacher*, 87(9), 698-701.
- Bailey, E. C., & Chen, F. (2005). Graphing portfolios in calculus. *Mathematics Teacher*, 98(6), 404-407.
- Bangert-Drowns, R. L., Hurley, M. M., & Wilkinson, B. (2004). The Effects of School-Based Writing-to-Learn Interventions on Academic Achievement: A Meta-Analysis. *Review of Educational Research*, 74(1), 29-58.
- Barker, T., Sturdivant, V., & Smith, H., Jr. (1999). *Adult students in the college classroom* (No. ED 434631).
- Barr, R. B., & Tagg, J. (1995). From teaching to learning: A new paradigm for undergraduate education. *Change*, 27(6), 13-25.
- Bazerman, C., Little, J., Bethel, L., Chavkin, T., Fouquette, D., & Garufis, J. (2005). *Reference guide to writing across the curriculum*. West Lafayette, IN: Parlor Press.

- Berenson, S. B., & Carter, G., S. (1995). Changing assessment practices in science and mathematics. *School Science & Mathematics*, 95(4), 182.
- Biggs, J. (2001). Assessment of student learning: Where did we go wrong? *Assessment Update*, 13(6), 6-7,11.
- Birken, M. (1989). Using writing to assist learning in college mathematics classes. In P. Connolly & T. Vilardi (Eds.), *Writing to learn mathematics and science*. New York, NY: Teachers College Press.
- Black, P., Harrison, C., Lee, C., Marshall, B., & Wiliam, D. (2004). Working inside the black box: Assessment for learning in the classroom. . *Phi Delta Kappan*, 86(1), 9-21.
- Black, P., & Wiliam, D. (1998). Inside the black box. *Phi Delta Kappan*, 80(2), 139.
- Borasi, R., & Rose, B. J. (1989). Journal writing and mathematics instruction. *Educational Studies in Mathematics*, 20(4), 347-365.
- Britton, J., Burgess, T., Martin, N., McLeod, A., & Rosen, H. (1975). *The development of writing abilities (11-18)*. London: Macmillan Education LTD.
- Brown, A. (1987). Metacognition, executive control, self-regulation and other more mysterious mechanisms. In F. E. Weinert & R. H. Kluwe (Eds.), *Metacognition, Motivation, and Understanding* (pp. 65-116). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Burkam, D. T. (1992). Teaching mathematics within the writing curriculum. In A. Sterrett (Ed.), *Using Writing to Teach Mathematics*. Washington, D.C.: The Mathematical Association of America.
- Burton, L. L. (1984). Mathematical thinking: The struggle for meaning. *Journal for Research in Mathematics Education*, 15(1), 35-49.
- Burton, M. (1992). Attempting mathematics in a meaningless language. In A. Sterrett (Ed.), *Using Writing to Teach Mathematics*. Washington, D.C.: The Mathematical Association of America.
- Carr, M. (2010). The importance of metacognition for conceptual change and strategy use in mathematics. In H. Salatas Walters & W. Schneider (Eds.), *Metacognition, Strategy Use, & Instruction* (pp. 176-197). New York, NY: The Guilford Press.
- Chickering, A. W., & Gamson, Z. F. (1987). Seven principles for good practice in undergraduate education. *AAHE Bulletin*, 39(7), 3-7.
- Cicmanec, K. M., & Viechnicki, K. J. (1994). Assessing mathematics skills through portfolios: Validating the claims from existing literature. *Educational Assessment*, 2(2), 167.

- Clarke, D. J., Waywood, A., & Stephens, M. (1993). Probing the structure of mathematical writing. *Educational Studies in Mathematics*, 25(3), 235.
- Cobb, P. (1986). Contexts, goals, beliefs, and learning mathematics. *For the learning of mathematics*, 6, 2-9.
- Cohen, J. (1988). *Statistical power and analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Connolly, P. (1989). Writing and the ecology of learning. In P. Connolly & T. Vilardi (Eds.), *Writing to learn mathematics and science* (pp. 1-14). New York, NY: Teachers College Press.
- Countryman, J. (1992). *Writing to learn mathematics strategies that work*. Portsmouth, NH: Heinemann.
- Creswell, J. W. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks, CA: SAGE Publications.
- Creswell, J. W., & Plano Clark, V. L. (2007). *Designing and conducting mixed methods research*. Thousand Oaks, CA: Sage Publications.
- Cross, K. P. (1981). *Adults as learners: Increasing participation and facilitating learning*. San Francisco: Josey-Bass.
- Davies, M. A., & Wavering, M. (1999). Alternative assessment: New directions in teaching and learning. *Contemporary Education*, 71(1), 39.
- Desoete, A., Roeyers, H., & Buysse, A. (2001). Metacognition and mathematical problem solving in Grade 3. *Journal of Learning Disabilities*, 34(5), 435-449.
- Dewey, J. (1938). *Experience and education*. New York, NY: Touchstone.
- DiBartolo. (2000). *Writing opportunities as a teaching/learning tool in a college mathematics course*. Columbia University.
- Dugan, J. J. (2007). *A systematic review of interventions in secondary mathematics with at-risk students: Mapping the literature*. Colorado State University, Fort Collins, CO.
- Emig, J. (1977). Writing as a mode of learning. *College Composition and Communication*, 28(2), 122-128.
- English, L. (2005, December). Ethical concerns related to journal writing. Unpublished paper presented for Techniques for Teaching Adults: A Motivational and Reflective Approach, through Starlink, an Agency of Texas Association of Community Colleges.

- Erzberger, C., & Kelle, U. (2003). Making inferences in mixed methods: The rules of integration. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behaviorial research* (pp. 457-488). Thousand Oaks, CA: Sage.
- Ewell, P. T. (1991). To capture the ineffable: New forms of assessment in higher education. *Review of Research in Education*, 17, 75-125.
- Ewell, P. T. (2008). Assessment and accountability in america today: Background and context. *New Directions for Institutional Research*(S1), 7-17.
- Ewing, S. C. (1998). Alternative assessment: popularity, pitfalls, and potential. *Assessment Update*, 10(1), 1.
- Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, 34(10), 906-911.
- Flavell, J. H. (1987). Speculations about the nature And development of metacognition. In F. E. Weinert & R. H. Kluwe (Eds.), *Metacognition, Motivation, and Understanding* (pp. 21-29). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Fusco, D. R. (1995). *The role of strategy, effort, and unknown attributions in a metacognitive model of mathematical problem solving*. City University of New York.
- Ganguli, A., & Henry, R. (1994). *Writing to learn mathematics: An annotated bibliography*. Minneapolis, MN: University of Minnesota.
- Garcia, G. E., & Pearson, P. D. (1994). Assessment and diversity. *Review of Research in Education*, 20, 337-391.
- Garofalo, J. (1989). Beliefs and their influence on mathematical performance. *Mathematics Teacher*, 82(7), 502-505.
- Garofalo, J., & Lester, F. K. (1985). Metacognition, cognitive monitoring, and mathematical performance. *Journal for Research in mathematics education*, 16(3), 163-176.
- Goos, M. (1994). Metacognitive decision making and social interactions during paired problem solving. *Mathematics Education Research Journal*, 6(2), 144-165.
- Goos, M., Galbraith, P., & Renshaw, P. (2002). Socially mediated metacognition: creating collaborative zones of proximal development in small group problem solving. *Educational Studies in Mathematics*, 49(2), 193-223.
- Gopen, G. D., & Smith, D. A. (1990). What's an assignment like you doing in a course like this?: Writing to learn mathematics. *College Mathematics Journal*, 21(1), 2-19.
- Graue, M. E. (1993). Integrating theory and practice through instructional assessment. *Educational Assessment*, 1(4), 293-309.

- Haley-James, S. (1982). Helping students learn through writing. *Language Arts*, 59(7), 726-731.
- Hanson, W. E., Creswell, J. W., Plano Clark, V. L., Petska, K. S., & Creswell, J. D. (2005). Mixed methods research designs in counseling psychology. *Journal of Counseling Psychology*, 52(2), 224-235.
- Herman, J. L., Aschbacher, P. R., & Winters, L. (1992). *A practical guide to alternative assessment*. Alexandria, VA: Association for Supervision and Curriculum Development.
- Herrmann, B. A. (1990). Cognitive and metacognitive goals in reading and writing. In G. Duffy (Ed.), *Reading in the Middle School* (pp. 81-96). Newark: International Reading Association.
- Hlebowitsh, P. S. (1995). A higher pragmatism: Assessment in the college curriculum. *Peabody Journal of Education*, 70(3), 160-174.
- Huba, M. E., & Freed, J. E. (2000). *Learner-centered assessment on college campuses*. Needham Heights, MA: Allyn and Bacon.
- Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, 33(7), 14-26.
- Kearsley, G. (2010). The theory into practice database. Retrieved August 20, 2010, from <http://tip.psychology.org/cross.html>
- King, N. (1998). *Qualitative methods and analysis in organizational research: A practical guide*. London: Sage.
- Knowles, M. S. (1973). *The adult learner: A neglected Species*. Houston: Gulf Publishing Company.
- Linn, R. (1993). Educational assessment: expanded expectations and challenges. *Educational Evaluation and Policy Analysis*, 15(1), 1-16.
- Lucangeli, D., & Cornoldi, C. (1997). Mathematics and metacognition: What is the nature of the relationship? *Mathematical Cognition*, 3(2), 121-139.
- Mayer, J., & Hillman, S. (1996). Assessing students' thinking through writing. *The Mathematics Teacher*, 89(5), 428-432.
- McLeod, D. B. (1992). Research on the affect and mathematics education: A reconceptualization. In D. A. Grouws (Ed.), *Handbook on research on mathematics teaching and learning* (pp. 575-596). New York: Macmillan.
- Meier, J., & Rishel, T. (1998). *Writing in the teaching and learning of mathematics* (Vol. 48): Mathematical Association of America, Washington D. C.

- Merriam, S. B. (2002). *Qualitative research in practice: Examples for discussion and analysis*. San Francisco, CA: Jossey-Bass.
- Merriam, S. B., & Caffarella, R. S. (1999). *Learning in adulthood: A comprehensive guide* (2nd ed.). San Francisco: Jossey-Bass.
- Mevarech, Z. R. (1999). Effects of metacognitive training embedded in cooperative settings on mathematical problem solving. *The Journal of Educational Research*, 92(4), 195-205.
- Miller, L. D. (1991). Writing to learn mathematics. *The Mathematics Teacher*, 84(7), 516-521.
- Miller, L. D. (1992). Teacher benefits from using impromptu writing prompts in algebra classes. *Journal for Research in Mathematics Education*, 23(4), 329-340.
- Morgan, G. A., Gliner, J. A., & Harmon, R. J. (2006). *Understanding and evaluating research in applied and clinical settings*. Mahaw, NJ: Lawrence Erlbaum Associates.
- Morgan, G. A., Leech, N. L., Gloeckner, G., & Barrett, K., C. (2004). *SPSS for introductory statistics: Use and interpretation*. Mahwah, N.J.: Lawrence Erlbaum Associates.
- Muis, K. R. (2004). Personal epistemology and mathematics: A critical review and synthesis of research. *Review of Research in Education*, 74(3), 317-377.
- Nahrgang, C. L., & Petersen, B. T. (1986). Using writing to learn mathematics. *The Mathematics Teacher*, 79(6), 461-465.
- National Center for Educational Statistics. Retrieved October 25, 2009, from http://nces.ed.gov/surveys/international/IntlIndicators/pdf/2007006_firstuniv_degrees.pdf
- National Center for Research on Evaluation, Standards, & Student Testing. Retrieved June 2, 2009, from <http://www.cse.ucla.edu/products/glossary.html>
- National Commission on Excellence in Education. (1983). A nation at risk: The imperative for educational reform. *The Elementary School Journal*, 84(2), 112-130.
- National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics*. Reston, VA: The Council.
- National Council of Teachers of Mathematics. (1991). *Professional standards for teaching mathematics*. Reston, VA: The Council.
- National Council of Teachers of Mathematics. (1995). *Assessment standards for school mathematics*. Reston, VA: NCTM.
- National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: NCTM.

- National Governors' Association. (1986). *Time for results*. Washington, D.C.: National Governors' Association.
- National Institute of Education. (1984). *Involvement in learning: Realizing the potential of American higher education*. Washington, D.C.: U.S. Department of Education.
- National Research Council. (2001). *Classroom assessment and the national science education standards*. Washington, D.C.: National Academy Press.
- Nevo, V., & Nevo, I. (2009). Conflicting findings in mixed methods research: An illustration from an Israeli study on immigration. *Journal of Mixed Methods Research*, 3(2), 109-128.
- Newell, G. E. (1984). Learning from writing in two content Areas: A case study/protocol analysis. *Research in the Teaching of English*, 18(3), 265-287.
- Newell, G. E., & Winograd, P. (1989). The effects of writing on learning from expository text. *Written Communication*, 6(2), 196-217.
- Niemi, D., Vallone, J., & Vendlinski, T. (2006). *The Power of big ideas in mathematics education: Development and pilot testing of POWERSOURCE assessments* (No. 697). Los Angeles, CA: CRESST/UCLA.
- Oladunni, M. O. (1998). An experimental study on the effectiveness of metacognitive and heuristic problem solving techniques on computational performance of students in mathematics. *International Journal of Mathematical Education in Science & Technology*, 29(6), 867-874.
- Peterson, M. W., & Einarson, M. K. (2001). What are colleges doing about student assessment? Does it make a difference? *The Journal of Higher Education*, 72(6), 629-669.
- Pintrich, P. R. (2002). The role of metacognitive knowledge in learning, teaching, and assessing. *Theory Into Practice*, 41(4), 220.
- Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Research in Education*, 63(2), 167-199.
- Powell, A. B., & Lopez, J. A. (1989). Writing as a vehicle to learn mathematics: A case study. In P. Connolly & T. Vilardi (Eds.), *Writing to Learn Mathematics and Science*. New York, NY: Teachers College Press.
- Pugalee, D. K. (2001). Writing, mathematics, and metacognition: Looking for connections through students' work in mathematical problem solving. *School Science & Mathematics*, 101(5), 236.
- Reif, M. (1995). Alternative assessment for adult learners. *Adult Learning*, 6(3), 12.

- Reilly, E. M. (2007). *Writing to learn mathematics: A mixed methods study*. Indiana University of Pennsylvania.
- Romberg, T. A. (1992). Assessing mathematics competence and achievement. In A. R. Tom (Ed.), *Toward a New Science of Educational Testing & Assessment* (pp. 23-52). Albany: State University of New York Press.
- Romberg, T. A., Zarinnia, A. E., & Collis, K. F. (1990). A new world view of assessment in mathematics. In G. Kulm (Ed.), *Assessing Higher Order Thinking in Mathematics*. Washington, D.C.: American Associate for the Advancement of Science.
- Rose, B. J. (1989). Writing and mathematics: Theory and practice. In P. Connolly & T. Vilardi (Eds.), *Writing to learn mathematics and science* (pp. 15-30). New York, NY: Teachers College Press.
- Rose, B. J. (1992). Using expressive writing to support mathematics instruction: Benefits for the student, teacher, and classroom. In A. Sterrett (Ed.), *Using Writing to Teach Mathematics*. Washington, D.C.: The Mathematical Association of America.
- Rossing, B. E., & Neuman, T. P. (1993). A reflective practice and evaluation how and why? *Adult Learning*, 5(2), 25-26.
- Russell, D. R. (1992). American origins of the writing-across-the curriculum movement. In C. Bazerman & D. R. Russell (Eds.), *Landmark Essays on Writing Across the Curriculum*. Davis, CA: Hermagoras Press.
- Schoenfeld, A. H. (1987). What's all the fuss about metacognition? In A. H. Schoenfeld (Ed.), *Cognitive Science and mathematics education* (pp. 189-215). Hillsdale, NJ Erlbaum.
- Schoenfeld, A. H. (1988). When good teaching lead to bad results: The disasters of "well taught" mathematics classes. *Educational Psychologist*, 23, 145-166.
- Schoenfeld, A. H. (1989). Exploration of students' mathematical beliefs and behavior. *Journal for Research in Mathematics Education*, 20, 338-355.
- Schoenfeld, A. H. (1992). Learning to think mathematically: Problem solving, metacognition and making sense in mathematics. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 334-370). New York: Macmillan.
- School of Health and Human Sciences- University of Huddersfield. What is template analysis? Retrieved August 6, 2009, from http://www.hud.ac.uk/hhs/research/template_analysis/whatis.htm
- Sen, M. (1998). Alternate assessments in a high school geometry class: Portfolios. *Thresholds in Education*(August), 30-35.

- Shepard, L. A. (2000). The role of assessment in a learning culture. *Educational Researcher*, 29(7), 4-14.
- Shepard, L. A. (2001). The role of classroom assessment in teaching and learning. In V. A. Richardson (Ed.), *Handbook of research on teaching* (4th ed., pp. 1066-1101). Washington D.C.: American Educational Research Association.
- Shield, M., & Galbraith, P. (1998). The analysis of student expository writing in mathematics. *Educational Studies in Mathematics*, 36(1), 29-52.
- Sipka, T. (1992). Writing in mathematics: A plethora of possibilities. In A. Sterrett (Ed.), *Using Writing to Teach Mathematics*. Washington, D.C.: The Mathematical Association of America.
- Smith, M. K. (2002). Malcolm Knowles, informal adult education, self-direction and anadragogy. Retrieved July 10, 2009, from www.infed.org/thinkers/et-knowl.htm
- Sternberg, R. J. (2008). Assessing what matters. *Educational Leadership*, 65(4), 20-26.
- Stiggins, R. J. (1999). Assessment, student confidence, and school success. *Phi Delta Kappan*, 81(3), 191.
- Stiggins, R. (2004). New assessment beliefs for a new school mission. . *Phi Delta Kappan*, 86(1), 22-27.
- Stiggins, R. (2007). Assessment through the student's eyes. *Educational Leadership*, 64(8), 22-26.
- Suskie, L. (2009). *Assessing student learning: A common sense guide* (2 ed.). San Francisco, CA: Jossey-Bass.
- Tashakkori, A., & Teddlie, C. (1998). *Mixed methodology: Combining qualitative and quantitative approaches*. Thousand Oaks, CA: Sage Publications.
- Teddlie, C., & Tashakkori, A. (2008). *Foundations of mixed method research: Integrating quantitative and qualitative approaches in the social and behavioral sciences*. Thousand Oaks, CA: Sage.
- Thorndike, R. M. (1997). *Measurement and evaluation in psychology and education*. Upper Saddle River, NJ: Prentice Hall.
- Toutenburg, H. (2002). *Statistical analysis of designed experiments* (2nd ed.). New York, NY: Springer-Verlag.
- U.S. Department of Education. (2006). *A test of leadership: Charting the future of U.S. higher education*. Retrieved from <http://www.ed.gov/about/bdscomm/list/hiedfuture/reports/final-report.pdf>.

- Vygotsky, L. S. (1962). *Thought and language*. Cambridge: M.I.T. Press, Massachusetts Institute of Technology.
- Waywood, A. (1994). Writing to learn as a dimension of a student profile. *Educational Studies in Mathematics*, 27(4), 321-340.
- Wiggins, G. (1989). A true test: Toward more authentic and equitable assessment. *Phi Delta Kappan*, 70(9), 703-713.
- Wiggins, G. (1993). Assessment: Authenticity, context, and validity. . *Phi Delta Kappan*, 75(3), 200.
- Wiggins, G., & McTighe, J. (2005). *Understanding by design* (2nd ed.). Alexandria, VA: Association for Supervision and Curriculum Development.
- Wilson, A. L., & Burket, L. (1989). *What makes learning meaningful?* Paper presented at the Annual Meeting of the American Association for Adult and Continuing Education. Retrieved from <http://0-search.ebscohost.com/catalog.library.colostate.edu/login.aspx?direct=true&AuthType=cookie,ip,url,cpid&custid=s4640792&db=eric&AN=ED313586&site=ehost-live>
- Zinsser, W. (1988). *Writing to learn*. New York: Harper & Row.

Appendix A: Background Questionnaire

Background questionnaire: Please write legibly

Name: _____ Email: _____

1. Gender (check one) ☐ Male
☐ Female
2. Ethnicity (check one) ☐ African American ☐ Asian
☐ Caucasian ☐ Hispanic/Latino
☐ Native American ☐ Pacific Islander
☐ Other
3. Age: _____
4. Type of Student (check one): ☐ Full -time ☐ Part-time
(12 or more credits) (fewer than 12 credits)
5. Marital Status (check one): ☐ Married ☐ Single
☐ Divorced
6. Number of Children: ☐ Zero ☐ One
☐ Two ☐ Three or more

7. Work Status (check one): ☐ Full-time ☐ Part-time
☐ Work study ☐ Not working at this time
8. How did you complete the prerequisite for this course?
☐ Passed College Algebra at Aims with a C or better
☐ Took the ACCUPLACER (placement exam) and received a high enough score
☐ ACT score was high enough to place directly into the course
☐ Transferred in pre-requisite from another college
9. Why are you taking this course (check one):
☐ Required for major
☐ Needed another math elective
☐ Personal Interest
☐ Pre-requisite for Calculus and Calculus is required for my major
10. Have you completed ENG 121 (freshman composition) or an equivalent course at another college to satisfy your first general education requirement for **COLLEGE** level writing?
☐ YES ☐ NO
11. Have you complete writing assignments in **math courses** before?
(Check all that apply)
☐ Journal Entries on mathematical concepts
☐ Learning Logs for mathematical concepts/connections
☐ Threaded Discussions related to study skills or math concepts
☐ Essay Questions on Exams/Quizzes
☐ Essays about Math Concepts
☐ Narratives of Mathematical Steps
☐ None of the Above

Appendix B: Cover Letter

EFFECTS OF WRITING TO LEARN IN PRE-CALCULUS MATHEMATICS ON ACHIEVEMENT AND AFFECTIVE OUTCOMES FOR STUDENTS IN A COMMUNITY COLLEGE SETTING

Letter of Agreement from Institution

Researcher: Michelle (Shelly) Ray Parsons
Supervisor of the Research (Principle Investigator): Gene Gloeckner, Ph.D.

The purpose of this study is to provide empirical evidence of students' overall academic achievement as well as their mathematic conceptual growth in addition to their metacognitive growth by using writing to learn mathematics. To answer the question of how and why writing to learn mathematics benefits students, qualitative and quantitative data will be collected and analyzed from classroom activities and course assignments. The benefits of this study will potentially result in an improved understanding of strategies for assessing mathematics which result in a better picture of who students are as learners and what the students really know, can do, and understand about the course and themselves as learners.

The research is for inclusion in a doctoral dissertation as fulfillment of the researcher's PhD program at Colorado State University. Portions of the program were previously funded by a National Science Foundation Grant Project

investigating the achievement gap related to math and science education.

Qualitative data and quantitative data will be collected from class activities and course work. An institutional review processes for data collection has been filed with both Colorado State University and Aims Community College. All Human Subjects research protocol for both institutions will be followed at all times.

By consenting to participate, you are indicating that you have read and understand the information related to this research. Be assured that there will be little or no risk to subjects due to the anonymity tied to your involvement in the research. All records will be kept on campus in secure files. All consent forms will be held in confidence until the end of the term and grades are submitted. By signing the consent you also understand that at any time if you feel uncomfortable, you have the right to end your participation without negative consequences. Once grades are submitted, consent forms will be shared with the researcher (Shelly) for data analysis.

If there are any questions please feel free to contact Shelly Ray Parsons at shelly.parsons@aims.edu , Randy Boan at randy.boan@aims.edu or, the supervisor of the research, Gene Gloeckner at Gene.Gloeckner@Colostate.edu or the Human Research Compliance Administrator (CSU) at 970-491-1655.

Or, for other questions, contact the Director of Research Analytics & Reporting for Aims Community College (937-512-2854).

Appendix C: Consent Form

CONSENT TO PARTICIPATE IN A RESEARCH STUDY COLORADO STATE UNIVERSITY

**TITLE OF STUDY - EFFECTS OF WRITING TO LEARN IN PRE-CALCULUS
MATHEMATICS ON ACHIEVEMENT AND AFFECTIVE OUTCOMES FOR STUDENTS IN
A COMMUNITY COLLEGE SETTING: A MIXED METHODS APPROACH**

- Principal Investigator: **Gene Gloeckner Ph.D., Colorado State University, 970-491-6835** Gene.Gloeckner@colostate.edu
- Co-Principal Investigator: Student (Researcher): **Michelle (Shelly) Ray Parsons, Professor of Mathematics, Aims Community College and Doctoral Fellow, Center for Learning and Teaching in the West, Colorado State University, 970 339-6368** or shelly.parsons@aims.edu

1. WHAT IS THE PURPOSE OF THE STUDY?

The purpose of this study is to provide empirical evidence of students' overall academic achievement as well as their mathematic conceptual growth in addition to their metacognitive growth (possible expansion of students' reflective capacity on thinking about their own thinking related to their learning of mathematics) by using writing to learn mathematics.

2. WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH?

You are enrolled in a section of the course at the institution where writing to learning mathematics is part of the course.

3. WHO IS DOING THE RESEARCH?

Shelly Ray Parsons, your professor for the course, is the primary person who will conduct the research.

4. WHAT WILL I BE ASKED TO DO?

We are asking you to allow information from coursework to be included as data in the research. You will not be asked to do anything above and beyond what is expected in the course other than complete a demographics form that will be linked to your coursework. Your work will not be identified by name in any of the data collection. The demographic information will be use for the sole purpose of describing the participants of the research and to examine equivalence of groups of participants involved in the research.

WHAT ELSE DO I NEED TO KNOW?

Your participation, or non-participation, will not have any effect on your grade or status with Professor Parsons or Aims Community College. Professor Parsons will not know who has agreed to participate until grades have been finalized.

Page 1 of 3 Participant's initials _____ Date _____

WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY?

There is no compensation for your participation in this study.

WHERE IS THE RESEARCH GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The data to be included in the study is a result of your work in the course. The study will last the entire semester and include exams scores as well as samples of the writing assessments required in the course.

ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS RESEARCH?

There are no reasons why you should not take part in the study.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

There are no known risks associated with the study.

*You may feel uncomfortable using writing to learn mathematics because you may not have experienced writing in a math course before. Because writing is included as part of the course, there is no risk associated with the study. You will be asked to write as part of your grade for the course from which the data is being collected.

WILL I BENEFIT FROM TAKING PART IN THIS STUDY?

There are no direct benefits in participating. Currently, research in Calculus and College Algebra courses show benefits for students using writing to learn mathematics. In this study, we hope to gain more knowledge about the effects of writing to learn on student achievement, conceptual growth, as well as promote self-reflection. In addition, this knowledge may benefit mathematics educators who will be able to modify their assessments to address these ideas for all students.

DO I HAVE TO TAKE PART IN THE STUDY?

Your participation in this study is voluntary. If you decide to participate in the study, you may withdraw your consent and you may stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

If you decide withdraw from the study, please contact Randy Boan at randy.boan@aims.edu and indicate your desire to withdraw. Professor Boan, a member of the mathematics department at Aims Community College and a person external to this research, has agreed to hold all consent forms until the end of the term. He will keep all information connected to participation or non-participation in confidence until grades are finalized. This is his only involvement with the study.

WHAT WILL IT COST ME TO PARTICIPATE?

There are no costs to participate in the study.

WHO WILL SEE THE INFORMATION THAT I GIVE?

We will keep private all research records that identify you, to the extent allowed by law.

Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private. When highlighting a specific participant in any case study, fictitious names, initials, or numbers will be used to protect your identity.

WHAT HAPPENS IF I AM INJURED BECAUSE OF THE RESEARCH?

The Colorado Governmental Immunity Act determines and may limit Colorado State University's and Aims Community College's legal responsibility if an injury happens because of this study. Claims against the University or College must be filed within 180 days of the injury.

WHAT IF I HAVE QUESTIONS?

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the Principal Investigator, Gene Gloeckner at 970-491-7661 or Gene.Gloeckner@colostate.edu or Co-Principal Investigator Shelly Ray Parsons at 970 339-6368 or shelly.parsons@aims.edu

Or, for other questions, contact the Director of Research Analytics & Reporting at Aims Community College (937-512-2854).

Page 2 of 3 Participant's initials _____ Date _____

Your signature acknowledges that you have read the information listed and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing 3 pages.

Signature for Consent to Participate in Research Study

Subject Printed Name: _____ Date: _____

Subject Signature: _____ Date: _____

Co-Principal Investigator: Michelle Ray Parsons

Co-Principal Investigator Signature: _____

Date: _____

Page 3 of 3 Participant's initials _____ Date _____

Appendix D: Learning Biography

The first writing assignment for the term is autobiographical essay titled, My Learning Biography: Who Am I? .

Students will address the following

- 1) who they are as a student
- 2) feelings they have toward mathematics in general
- 3) their strengths as a mathematics student
- 4) goals for this course
- 5) long term educational goals
- 6) and why you feel you will be successful in this course

Do not tell me what grade you want to earn. Tell me who you are as a learner.

Appendix E: End of Term Essay

The overall theme of this essay is the growth you have experienced as a learner over this term. Refer to in class activities, course projects, the opportunity to work with other students, the WebCT discussions, your portfolio, and your progress in the course to demonstrate that growth. Please address the following questions.

- 1) What is your vision of a successful learner? Do you feel that you have accomplished your goals this semester? Explain what your goals were and why you feel you met or didn't meet your goals. *I do not want to hear about the grade you expect but what you learned about yourself as a learner.*
- 2) How have you changed as a learner this term? You were asked to "do some different things in a math class" in this course that were intended to help you to grow as a learner. Did you change at all in terms of how you approach learning math? Why or why not?
- 3) Finally, do you feel that writing to learn mathematics required you to reflect on what you really know, understand, and can do with respect to trigonometry? Even if you did not "enjoy" the process, do you see a connection to writing and reflecting on what you have learned? How do you expect to use writing in your future profession?
Please write a detailed example for this experience.
Conclude your essay with a description of how you monitor your learning "then and now"

The title of your essay should be "That Was Then, This Is Now" It is a minimum of 3 pages double space typed with 12 point font and 1 inch margins on all sides. You are required to use Times New Roman or Verdana as the font.

Appendix F: Threaded Discussion Question

Threaded discussions are a learning journal of various writing assessments over the course of the term. These assessments involve self-reflection and analysis of mathematical/personal growth. Content and study skills will be addressed in these prompts. Discussion prompts and reply timelines are indicated on the course calendar. Student will be required to post in total **three times per prompt** to receive full credit. Post once to my initial prompt and then respond intelligently to another student's prompt. A third post can either be a reply to a different student or reply to a student who asked you for clarification. Initial prompts must be responded to **by Wednesday at midnight MST**. Replies to students must be posted **by the following Sunday at midnight MST**. Journal prompts will be completed and posted via WebCT.

Prompt 2

In this course, we have made numerous connections to the unit circle. Please post ONE of the connections you see and explain it in detail.

Post a unique connection. This means you need to read others posts BEFORE you post your own.

In addition, discuss what you feel has been the most profound connection that furthered your understanding of trigonometry.

Appendix G: Mathematical Growth Journal Entry

Additional work included in the course portfolio which demonstrates students' mathematical growth are represented through mathematical growth journal entries. Students choose what to include and provide a type-written reflection for each item chosen. This section must have a minimum of three items included. Students are to choose from assignments, in class activities, and class projects from a chapter which they feel shows the most mathematical conceptual growth. Students may choose any combination of examples of their work that represents their growth. A reflective piece, 1 to 2 paragraphs in length per selection, detailing why this specific assignment, in class activity, or class project was chosen will complete this section of the course portfolio.

All students were required to write about one of three key activities/projects that are part of the course.

Building the Unit Circle on a paper plate