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An Examination of the Impact of Smart Pen Technology on Mathematics Achievement and Attitudes of Community College Students

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AN EXAMINATION OF THE IMPACT OF SMART PEN TECHNOLOGY ON MATHEMATICS ACHIEVEMENT AND ATTITUDES OF COMMUNITY COLLEGE STUDENTS

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ABSTRACT

This study sought to examine the impact of instructional use of smart pen technology on the mathematics achievement and attitudes of community college students enrolled in a College Algebra course. This quasi-experimental, mixed-methods study utilized a nonequivalent control-group design. In this study, two sections of College Algebra were analyzed with one section serving as a treatment group which had access to an online archival of smart pen documents. The other section served as a control group which had access to an online archival of digital documents which did not have smart pen capabilities. The first hypothesis sought to analyze the effect of the pen on students' mathematics achievement. Pretest and posttest data were collected from students in both sections. Using an ANCOVA test, results indicated that there was no significant difference in mean mathematics achievement scores by instructor's use of the smart pen as an instructional aid when controlling for pretest scores.

The second hypothesis examined the number of times students viewed the online documents. The online communication platform collected data regarding how often each document was accessed by the students. Using a one-way chi square test, results indicated there was no significant difference in the distribution of student views of online course notes by the existence of smart pen documents for instructional use.

The third research question investigated student attitudes regarding mathematics. This question was explored qualitatively using participant interviews from each group. Using an interview protocol, the researcher questioned students about their attitudes toward mathematics, mathematics self-efficacy, use of the online documents, and satisfaction with the course.

Responses of the interviews indicated that participants from each group held different views of how the documents should be utilized. Students from the treatment group also seemed to be more satisfied with their understanding attained in the course.

Findings indicated that the instructor’s use of smart pen technology did not significantly impact student achievement or attitudes. This lack of significance could be attributed to the low number of students who actually accessed the documents. The findings indicate the need for further research regarding the effects of smart pen technology.

DEDICATION

This dissertation is dedicated to my parents, Micheal and Debra Marolt, who have always been my biggest fans.

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CHAPTER 1: INTRODUCTION

Introduction

International comparisons have given United States mathematics educators cause for growing concern. These comparisons have indicated disturbing statistics regarding the mathematics performance of U.S. students when compared with students from other countries. In the Third International Mathematics and Science Study (TIMSS), U.S. students in fourth grade scored below eight other countries, including Hong Kong, Singapore, and Chinese Taipei (National Center for Educational Statistics [NCES], 2009). According to this same report, U.S. students in eighth grade scored below five of the other participating countries. More alarming are the results of the Program for International Student Achievement (PISA). This program, which evaluates mathematics literacy, indicated that American 15-year-olds scored lower than the average of participating countries in the Organization for Economic Cooperation and Development (OECD). Students in 23 of the 29 OECD participating countries outperformed U.S. students, placing U.S. students in the bottom quarter of countries who took part in this study (NCES, 2009). These statistics indicate a need for change in mathematics education in order to increase student achievement in the United States.

In *The Teaching Gap*, Stigler and Hiebert (1999) noted that one of the biggest obstacles facing American educators is their lack of strategy for improving classroom instruction. There have been studies, however, that have shown a positive relationship between the use of technology and student attitudes in the classroom (Chen & Howard, 2010; Ku, Harter, Liu, Thompson, & Cheng, 2007; Lee & Chen, 2010). Research also has shown a significant link between student attitudes and achievement in the mathematics classroom (Higbee & Thomas, 1999; Ma & Kishor, 1997; Muis 2004). Therefore, the implementation of technology in the mathematics classroom holds the potential for increasing student achievement.

The *Principles and Standards for School Mathematics* (National Council of Teachers of Mathematics [NCTM], 2000) presents a positive and compelling argument for the use of technology in the mathematics classroom. The authors of this document stated that technology is essential in mathematics education. Furthermore, they noted that technology helps students learn and aids teachers by supporting effective instruction. The use of technology, however, has not always been supported by other groups, such as the National Mathematics Advisory Panel (National Mathematics Advisory Panel [NMAP], 2008). This panel of experts recommended that computers be used in the mathematics classroom for drill practice and that the use of computer programming be considered as an effective tool for elementary students. With regard to calculators, however, the panel gave no recommendation for their use in the classroom (NMAP, 2008). Because of their restrictive use of scientific research, the NMAP identified only one study in the past twenty years as scientific and rigorous enough to be considered for their recommendations regarding the use of calculators in the classroom. Basing decisions on this research is therefore problematic as the introduction of handheld graphing utilities has made calculators more accessible in the past twenty years.

According to Hiebert (2003), conclusions regarding the use of calculators in the classroom are difficult to make because it is hard to isolate the effect of calculators from other factors surrounding its implementation, such as the instructor and the curriculum. In response to these issues, Hiebert stated the answer to whether calculators should be used in the classroom will not be answered with a single study about their effects on students' understanding. He noted that to make a confident recommendation for the implementation of calculators in the mathematics classroom, it will take the analysis of trends found from many studies.

This idea can be transferred to any type of technology used in the mathematics classroom. Research on technology in the mathematics classroom has primarily involved three tools, namely the graphing calculator, dynamic geometry software, and computer algebra systems (CAS) (Ellington, 2006; Hong, Thomas, & Kiernan, 2000; Isiksal & Askar, 2005). Research surrounding these tools has shown that the use of technology has a positive effect on student attitudes. This research also indicated that the use of these technological tools does not hinder and often improves student achievement scores. As Hiebert (2003) pointed out, a database of several reliable studies with similar results is needed to make a strong recommendation for the use of any technological tool in the classroom.

While a variety of technologies have been used in mathematics education, the introduction of the smart pen for commercial use has given educators the opportunity for implementation of a new technology in the classroom. Because of its recent release, little research has been conducted to examine the effectiveness of the smart pen in the mathematics classroom. Research regarding this new tool will provide valuable information for administrators and mathematics educators to draw on when making instructional decisions regarding the implementation of this new technology.

Statement of the Problem

Among the research regarding technology, none has been conducted about the use of the smart pen in the mathematics classroom. The potential reason for this is its availability. The smart pen was only released for commercial use in 2008. This has given researchers, aside from those endorsed by the manufacturer, little time to perform and publish research on its effectiveness. The problem addressed by this study was this lack of research regarding the impact of instructional use of the smart pen on student achievement and attitudes in the mathematics classroom.

Purpose

The purpose of this mixed-methods, quasi-experimental study was to examine the impact of the smart pen as an instructional aid. Specifically, it investigated its impact on community college students' mathematical achievement in the classroom and attitudes toward mathematics.

Research Questions and Hypotheses

The research questions analyzed in this study were as follows:

1. Do achievement scores of College Algebra students in a community college setting whose instructor utilizes smart pen technology differ significantly from similar students whose instructor does not utilize smart pen technology?
2. Is there a significant difference in the frequency of student views of online course notes between class sections with and without smart pen documents available?
3. What attitudes are characteristic of students in classrooms with and without instructor's use of the smart pen?

The first two research questions were used to formulate null hypotheses which were analyzed quantitatively. The null hypotheses were as follows:

Hypothesis 1

There will be no significant difference in mean mathematics achievement scores by instructor's use of the smart pen as an instructional aid when controlling for pretest scores.

Hypothesis 2

There will be no significant difference in the distribution of student views of online course notes by the existence of smart pen documents for instructional use.

Definitions

The following terms are defined to clarify their meaning within the scope of this study.

Smart Pen

This device has been marketed under several other pseudonyms. In this study, the smart pen device is that tool which records the user's pen strokes and simultaneously records the accompanying user's audio. This combination of visual and audio recording is captured digitally and can be saved and edited on a computer platform for later use. In this study, the instructor will be the user of the smart pen, recording lectures and examples electronically and posting them for students' personal use within an internet-based class information system.

Mathematics Achievement

Mathematics achievement will be referred to as a student's ability to perform procedures successfully on the type of traditional skills-based mathematics assessment required to complete the course successfully.

Student Attitudes

Student attitudes will be defined as students' general disposition toward the subject of mathematics, their feelings of self-efficacy in performing mathematical procedures, and their opinions towards their instructor's use of resources in the duration of the course.

Instructor

The instructor is defined to be the teacher of the course selected by the administration of the school. In this study, the instructor has been using the smart pen device as an instructional aid for one year prior to the study. The instructor is the designer and preparer of all electronic resources available to the students.

Significance

The authors of the *Principles and Standards for School Mathematics* stated, “Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students’ learning” (NCTM, 2000, p. 24). Studies have shown that the use of technology in the classroom has positively impacted student achievement scores (Harrison, Lunzer, Tymms, Taylor Fitz-Gibbon, & Restorick, 2004; Weiss, Kramarski, & Talis, 2006). In addition, most educators agree that student attitudes affect their achievement in the classroom (Higbee & Thomas, 1999; Ma & Kishor, 1997; Muis 2004). Yet many national organizations still call for more research on the effects of technology, such as calculators in the classroom (NMAP, 2008; National Research Council, 2001). Clearly, research is needed to supply administrators and instructors with information to make instructional decisions in the classroom. Therefore, measuring the impact of the smart pen on student achievement and attitudes is of interest to those seeking to identify and support students’ need for success in the mathematics classroom.

Chapter Summary

There is a national need for improving mathematics education. Technology holds the potential for significantly improving student attitudes and achievement. The purpose and significance of this study was to provide quality research for educators to use in making instructional decisions regarding digital pen technology. The following chapter provides a review of the literature surrounding the use of the smart pen as well as the use of other technological tools in the classroom.

CHAPTER II: LITERAURE REVIEW

Introduction

Due to studies noting U.S. students' poor mathematics achievement, there is a need to investigate the effectiveness of smart pen technology and its possible positive impact on student attitudes and achievement. Student attitudes have been shown to impact student achievement in the classroom (Higbee & Thomas, 1999; Ma & Kishor, 1997; Muis 2004). In turn, the use of technology has been linked to positive student attitudes in the mathematics classroom (Chen & Howard, 2010; Ku et al., 2007; Lee & Chen, 2010). Therefore, technology has the potential to impact student achievement in the mathematics classroom.

Notably absent from the body of instructional technology research is the study of smart pen technology. The potential reason for this absence is its recent release to the commercial market. This study investigated the impact of instructional use of the smart pen on student achievement and attitudes regarding mathematics.

This chapter provides a summary of the perspectives of national organizations on the use of technology in the mathematics classroom. Additionally, it provides a review of the literature on technological tools commonly used in the mathematics classroom. Finally, it contains a summary of the current research on smart pen technology and how it is being used.

Summary of National Perspectives on Technology in the Mathematics Classroom

Many national educational organizations have published standards for the ideal use of technology in the mathematics classroom. Each organization has sought to make recommendations on the use of technology to optimize student learning. The following paragraphs will describe the perspectives of the National Council of Teachers of Mathematics [NCTM], Association of Mathematics Teacher Educators [AMTE], International Society for Technology in Education [ISTE], and the National Mathematics Advisory Panel [NMAP].

NCTM

In 2000, the National Council of Teachers of Mathematics established six principles to provide a vision for school mathematics in the classroom. One of these principles was the Technology Principle which stated, “Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students’ learning” (NCTM, 2000, p. 24). The authors stated that the presence of technology affects what mathematics is taught, how mathematics is taught, and when mathematics is taught in the classroom. They explained that technology not only affects the complexity of material that can be taught in the classroom, but also affects the placement of that material in the curriculum. In addition, the authors stated that technology enhances the mathematics that is taught through explorations with multiple representations (NCTM, 2000). They explained that technology “blurs some of the artificial separations among topics in algebra, geometry, and data analysis” allowing students to make connections (p. 26). As previously stated, this influences the complexity and placement of material within the curriculum. According to this document, the “boundaries of the mathematical landscape are being transformed” (p. 27).

In 2003, the Commission on the Future of the Standards released *A Research Companion to the Principles and Standards for School Mathematics* (Kilpatrick, Martin, & Schifter, 2003). The purpose of this document was to review the research pertaining to the issues discussed in the *Principles and Standards for School Mathematics* (NCTM, 2000). In this document, Hiebert discussed the debate concerning the use of calculators in the mathematics classroom. Using results from available research, he stated that teachers could use calculators in their classroom wisely with some confidence. He also recommended that when negative results concerning students' learning with calculators were reported, the instructional program should be examined. He attributed this recommendation to the fact that the effect of the calculator is hard to distinguish from the other factors surrounding its implementation, such as the curriculum and the instructor. He suggested that no single study would provide conclusive research about the effectiveness of calculators in the classroom. He proposed that the best way to draw these types of conclusions was to look for patterns in multiple studies (Hiebert, 2003).

Following the release of the *Research Companion*, NCTM again took a stance when they issued two position statements regarding technology in the classroom. The first position statement, published in March of 2005, was entitled, "Computation, Calculators, and Common Sense" (NCTM, 2005). The organization said that there was indeed room for both computation and calculators in the classroom. It stated that students need to develop a wide range of skills to solve problems both in and out of the school. It also stated that a balanced mathematics program helps students develop confidence and the discernment of when and how to use the tools available.

The NCTM issued another position statement regarding technology in March of 2008 entitled, "The Use of Technology in the Learning and Teaching of Mathematics" (NCTM, 2008). The council stated that technology was essential in the twenty-first century and that all students should have access to technology. It also said that effective teachers utilize technology in a way that helps students develop understanding and proficiency in mathematics. It stated that when technology is used appropriately, it can give all students access to mathematics. The council also declared that “interactive presentation devices” are important in a “high-quality mathematics education” (para. 2).

AMTE

Other educational organizations have also made statements about their beliefs on technology in the classroom. In 2006, the Association of Mathematics Teacher Educators (AMTE) issued a position statement about the preparation of future educators and their use of technology in the classroom. They declared that teachers and teacher candidates must have access to opportunities to learn more about technology and how to incorporate the technology in the classroom. They stated it was the responsibility of teacher educators to allow teacher candidates to explore the uses of technology and model appropriate instruction using technology.

Their position statement also included a description of how technology could be used to enhance the teaching and learning of mathematics (AMTE, 2006). They stated that the use of technology could be used to facilitate understanding that would not otherwise be possible without its use. They also noted the capabilities of technology allow students to investigate multiple representations giving students a variety of ways to construct knowledge. These ideas were similar to those presented by NCTM in The Technology Principle which stated that technology “influences the mathematics that is taught and enhances students’ learning” (NCTM, 2000, p. 24).

ISTE

In 2008, the International Society for Technology in Education (ISTE) presented National Educational Technology Standards for Teachers. They stated that teachers should facilitate and inspire student learning and creativity, design and develop digital-age learning experiences and assessments, model digital-age work and learning, promote and model digital citizenship and responsibility, and engage in professional growth and leadership (ISTE, 2008). They also stated that teachers should use the standards set for students as they design and implement experiences with technology.

The National Educational Technology Standards for Students stated that students should be able to use technology to facilitate understanding and construct knowledge (ISTE, 2007). They also encouraged students to use technology to collect, organize, and synthesize data and use critical thinking skills to make informed decisions regarding this data. They also emphasized the role of technology in communication and promoted digital citizenship. These ideals echo those presented by the NCTM Technology Principle and the AMTE position statement regarding technology by emphasizing the role of technology in facilitating mathematical understanding.

NMAP

While NCTM, AMTE, and ISTE organizations encouraged the use of instructional technology, not all organizations have provided such support. In 2006, President George W. Bush organized the National Mathematics Advisory Panel to analyze current research on topics of interest in mathematics education and make recommendations for instruction (NMAP, 2008). The Panel's recommendations regarding technology provided mixed results.

The Panel made positive recommendations regarding the use of computer-assisted instruction in the classroom (NMAP, 2008). The Panel suggested that computer-assisted instruction could be dependably used for drill and practice. In addition, they recommended that computer-assisted instruction tutorials be implemented as a potentially useful tool in the classroom. They also recommended that instruction involving computer programming be considered as a useful tool in developing mathematical concepts and applications, especially for elementary school students.

The Panel's recommendations regarding the use of calculators in the classroom, however, were inconclusive (NMAP, 2008). The Panel recommended that "high-quality research on particular uses of calculators be pursued, including both their short- and long-term effects on computation, problem solving, and conceptual understanding" (p. 50). The Panel felt that there was a lack of the "best possible scientific evidence" upon which to make a strong recommendation for classroom use of the calculator (p. xiii). This lack of support was attributed to an absence of available research in the area of calculator technology.

The recommendations from the NMAP and other organizations appear to contain contradictions. The NCTM, AMTE, and ISTE organizations' recommendations concentrated on using technology to develop both procedural fluency and conceptual understanding of mathematics. The recommendations regarding technology from the NMAP appeared to focus strictly on students' procedural skills without consideration of conceptual understanding. This narrowly focused recommendation could be the result of their restrictive use of research when making those recommendations. For example, the Panel found only eleven "rigorous" and "scientific" studies upon which to base their recommendation concerning calculators and of those only one was conducted in the last twenty years. Therefore, the research on many updated technological tools that are currently used in the classroom was largely disregarded when making recommendations.

Summary

Many organizations have presented an ideal for implementation of technology in the mathematics classroom (NCTM, 2000; AMTE, 2006; ISTE, 2008). The NMAP sought to make recommendations for the use of technology based on scientific research, but failed to make a recommendation for calculators due to their restrictive use of research (NMAP, 2008). These mixed results might cause educators to look to the research itself for conclusions. The following section will review available scientific research regarding technology currently used in the mathematics classroom.

Research on Technology Commonly Used in the Mathematics Classroom

A review of the literature revealed three primary technological tools utilized in the mathematics classroom, namely the calculator, dynamic geometry software, and computer algebra systems. As a result, this section will focus on these tools as they have shaped today's mathematics classroom. The research will be reported in the following paragraphs, organized according to the three technological tools.

Calculators

Since its introduction, researchers have sought to measure the impact of the calculator in the mathematics classroom. In a study analyzing the effects of calculators in college level mathematics courses, Cassity (1997) examined the relationship between graphing calculator utilization and students' conceptual performance. The sample in this study consisted of 144 students enrolled in nine sections of College Algebra at a university in the Rocky Mountain region. Sections were rated for their calculator utilization and the third in-class exam was used to measure conceptual understanding. A panel of experts divided the exam into procedural and conceptual subscales.

The Pearson product-moment correlation coefficient was used to determine that there was no significant difference between calculator utilization and students' performance on test items evaluating conceptual understanding. This lack of significance could be attributed to the fact that all nine sections were ranked by calculator utilization between 6 and 9 on a scale of 3 to 15. This indicates little variation in calculator utilization among the nine sections.

In another study analyzing the effect of the graphing calculator on community college students' achievement in an introductory algebra class, eighteen students were given a pretest and survey to assess their basic mathematical knowledge and attitudes toward the use of the graphing calculator in mathematics learning (Reznichenko, 2006). Students were not allowed to use the graphing calculator on the pretest. Using mixed methods of delivery, students were then given a six-week intervention on how to use the graphing calculator, including lectures with examples from the textbook and collaborative learning exercises. No control group was considered.

At the conclusion of the intervention, students were given a posttest evaluating the topics covered in class (Reznichenko, 2006). Students were allowed to use the graphing calculator on this exam. Students were also administered another attitudinal survey after the intervention. Using a paired, one-tailed *t*-test to compare pretest and posttest scores, a significant gain was found in students' achievement scores. Using the same statistical test, the attitudinal surveys were compared and a gain in students' attitude was observed, although it was not significant. The researchers noted these results showed the implementation of the graphing calculator into the curriculum was successful.

Individual studies, however, cannot provide the generalizability necessary to make widespread instructional decisions. Regarding the use of calculators in the classroom, Hiebert (2003) stated that the best conclusions are drawn from analyzing trends across many studies. In a meta-analysis, Ellington (2003) included 54 of the over 120 studies she found that featured the effect of calculators in the classroom. After perusing academic databases, the criteria for final inclusion in the analysis were that the study was published between January 1983 and March

2002, it featured the use of a basic, scientific, or graphing calculator, and the report provided the information necessary to calculate effect sizes.

Ellington categorized the studies according to the skills they measured as operational, computational, conceptual, and problem solving (Ellington, 2003). In her meta-analysis, Ellington found that the most positive effects occurred when calculators were used as a part of both instruction and testing. Students showed an improvement on items that measured operational skills and conceptual understanding. In addition, the researcher found that students in classrooms that used calculators as a part of instruction reported better attitudes than those that did not.

In 2006, Ellington continued her research by conducting another meta-analysis to focus on the effects of graphing calculators without computer algebra system (CAS) capabilities on student achievement and attitudes. After a search for studies through education-related databases, a study was included in this analysis if it consisted of a treatment group that had access to calculators and a control group which did not. It also had to have the appropriate statistics for calculating effect sizes and it had to be performed in a mainstream precollege or college classroom.

The search yielded 42 studies, four of which did not specify if the calculator type allowed for testing was scientific or graphing (Ellington, 2006). Procedural skills, conceptual skills, and mathematics achievement were analyzed. In this study, the researcher defined procedural skills to mean those requiring “application of an algorithm, rule, or procedure to complete the problem at hand” and conceptual skills to be those “skills used to understand mathematics concepts and to apply those concepts to a variety of problem solving situations” (p.19). Twelve of the studies analyzed students' overall mathematical achievement after having access to graphing calculators during instruction.

The results showed that when calculators were used in instruction but not testing, calculators did not help or hinder students' ability to apply mathematical formulas and procedures or students' overall mathematics achievement (Ellington, 2006). Under the same conditions, however, the calculator was found to be an aid to students' conceptual understanding. When calculators were used in both instruction and testing, students benefitted from the use of the calculator in procedural understanding, conceptual understanding, and overall mathematics achievement. The study also found that the graphing calculator had a positive effect on student attitudes toward mathematics. She noted that no studies were found where students without access to calculators performed better than students with access to calculators.

Therefore, there is research available analyzing the trends of many studies regarding the use of calculators in the classroom. As Hiebert (2003) suggested, the analysis of several studies provides results which can used with more confidence. All of the previously mentioned studies demonstrated that when calculators were used in the classroom, positive results on student achievement were common. None of the studies provided evidence that calculators hindered student learning and all studies reported that student attitudes were improved by the use the calculator. Thus, the findings of these studies allow teachers to make instructional decisions concerning calculators with some assurance of positive results.

Dynamic Geometry Software

As with calculators, researchers have sought to examine the impact of dynamic geometry software. In one instance, the role of the teacher in the implementation of dynamic geometry software has been examined. In an international study, Laborde (2001) investigated teachers' integration of *Cabri* geometry software in a program that was designed to begin with first year high school students and continue over a period of three years. The *Cabri* geometry software was available to students on TI-92 calculators for use at home or in the classroom. A team of four teachers of various ability levels was formed to meet and collaborate monthly on implementation of the software in the classroom.

The researcher identified ways teachers used the software in class (Laborde, 2001). He noted that the novice teacher and the teacher with little technological experience designed activities where *Cabri* was used as a facilitating tool of the material aspects of the task. These same teachers, however, did not use *Cabri* to change the task conceptually. The more experienced teachers and those familiar with the technology designed tasks in which *Cabri* could be used to develop problem solving strategies not available without the use of such technology. The researcher concluded that “technology gives a meaning to mathematics and mathematics justifies the use of technology” (p. 316). These types of conclusions support instructional decisions to include visualization tools in the mathematics classroom.

In another international study involving Turkish students, Isiksal and Askar (2005) analyzed the effects of the visualization tool *Autograph* on the mathematics achievement of seventh grade students. The sample for this study consisted of 64 students with an equal number of male and female participants. Students were randomly assigned to classrooms using traditional-based instruction without the use of technology, instruction using spreadsheet software, or instruction using the dynamic geometry software, *Autograph*. To measure mathematics achievement, a test consisting of 20 short answer questions was developed by mathematics teachers at the school.

Based on a pre- and post-test design, the researchers found that the use of the visualization tool *Autograph* resulted in significantly greater mean mathematics achievement scores compared to that of comparison groups (Isiksal & Askar, 2005). The study also investigated students' mathematics and computer self-efficacy. When surveyed using a mathematics self-efficacy scale, students in the group using *Autograph*-based instruction rated themselves significantly higher than students in comparison groups. The results also showed a significant relationship between mathematics achievement post-test scores and students' computer self-efficacy scores. The authors noted that future research was needed to further examine the impact of geometry software and perceived efficacy on students' mathematics performance.

Hannafin and Scott (1998) studied the effects of another form of dynamic geometry software, *The Geometer's Sketchpad*. They sought to analyze the effects of the program on student recall of factual information and conceptual understanding after controlling for ability. The study's sample consisted of 210 eighth-grade students, with an equal distribution of males and females. The study took place in 12 algebra and prealgebra classrooms of different ability levels. The researchers stated that the school had historically low mathematics test scores.

Researchers used a reverse digit-span memory test and the Raven's Progressive Matrices test as well as students' year-to-date mathematics averages to determine students' ability levels. Students were given instruction developed by the researcher using *The Geometer's Sketchpad*. Researchers then administered a posttest, consisting of 45 items which evaluated factual recall and 11 items which evaluated conceptual understanding. The results of the study showed that high-achieving students performed better on factual recall items than low-achieving students.

The researchers also found, however, that low-achieving students performed better than high-achieving students on conceptual understanding items after using *The Geometer's Sketchpad*.

Dynamic geometry software can serve as an important tool providing students with multiple representations. Laborde (2001) suggested that the role of the teacher plays a significant role in the effectiveness of this tool. Hannafin and Scott (1998) also suggested that this tool has positive implications for low-achieving students. These studies provide evidence that dynamic geometry software can have a positive effect on student understanding and achievement.

Computer Algebra Systems

The introduction of computer algebra systems (CAS) into the classroom has given researchers cause to investigate its effectiveness in the mathematics classroom. When compared with other technological tools, the distinguishing characteristic of this tool is its symbolic manipulation capabilities. According to Heid and Edwards (2001), CAS perform four functions in the classroom: to serve as a primary producer of symbolic results; to create symbolic procedures; to help students generate examples with which to look for patterns; and to create results for problems posed in abstract form. They also report that these utilities allow students with little or no knowledge of algebraic properties to simplify expressions and solve equations.

Vlachos and Kehagias (2000) examined the role of CAS in a business calculus environment at a Greek university. In this study, the sample consisted of approximately 160 students in nine classes. Five of the nine classes received instruction which utilized CAS. The remaining four classes received traditional, non-computerized instruction. Student surveys indicated that students who received CAS instruction had markedly better attitudes than those who did not. Researchers used a prerequisite course grade to show that the groups were not significantly different before the treatment instruction.

Using the difference between a prerequisite math course grade and the business calculus course grade to evaluate mathematical proficiency, the researchers found a statistically significant difference between the mean grade differences of students enrolled in the classrooms using computer algebra systems and students enrolled in classrooms without access to computer algebra systems (Vlachos & Kehagias, 2000). In the business calculus course, students enrolled in the classrooms using computer algebra systems had a higher mean score than students enrolled in the traditional, non-computerized courses.

Another international study examined the effect of calculators with CAS capabilities on students' achievement, their scores on University Entrance Calculus Examinations, and their attitudes toward CAS (Hong et al., 2000). The students involved in this study were 17- and 18-year-olds at two different schools in New Zealand. Both a control group of students who did not have access to calculators with CAS capabilities and a treatment group which did have access to calculators with CAS capabilities existed at both schools.

The authors defined a calculator-positive test to be one on which the use of the TI-92 calculator with CAS capabilities might render an advantage and a calculator-neutral test to be one where the use of the TI-92 would not necessarily provide an advantage to test takers (Hong et al., 2000). To serve as a pretest, students were given a calculator-positive test constructed from questions set in the national Bursary Mathematics with Calculus university entrance examination for 1992-1997. Students then received instruction, with the control group receiving their usual instruction without the CAS and the treatment group receiving calculator-intensive instruction.

After receiving instruction, the students were administered a calculator-positive posttest and a calculator neutral posttest (Hong et al., 2000). Students in the experimental groups were allowed to use CAS on the test while students in the control group were allowed to use standard calculators. Results showed that students in the treatment group scored significantly better on the calculator-positive test than students in the control group. On the calculator-neutral test, students in the treatment group scored slightly lower than students in the control group, but not significantly. The researchers also found no significant difference on the scores of students in both groups on the Bursary Mathematics with Calculus university entrance examination.

For the qualitative portion of this study, researchers interviewed students about their attitudes toward CAS (Hong et al., 2000). Many students responded that CAS allowed them to develop new problem-solving strategies, solve problems faster, and improve conceptual understanding. Some students, however, stated that CAS encouraged them to focus on procedures and not gain conceptual understanding. These contrasting reports revealed the different effects CAS could have depending on the student.

The long term effects of using CAS in the classroom have also been analyzed. In a study analyzing the effectiveness of CAS in a developmental algebra course, researchers examined the effect of the use of CAS on students' performance in a subsequent introductory statistics course that was typically taken to fulfill their mathematics requirement for graduation (Shaw, Jean, & Peck, 1997). Students were categorized into three subdivisions: those who did not require developmental courses, those who took a traditional non-technology based Intermediate Algebra course, and those who took a technology based Intermediate Algebra course incorporating CAS into the classroom. There was disparity in sample sizes between the groups as 1335 students did not require a developmental algebra course, 109 students were included in the traditional non-technology based Intermediate algebra course, and 34 were included in the technology based Intermediate Algebra course. This disparity was due to student attrition and the fact that students did not take the subsequent statistics course within the time limits of the study.

The results showed that the mean introductory statistics grade for students who did not require a developmental algebra course and those who participated in the technology-based course were not significantly different (Shaw et al., 1997). The mean grade for those who participated in the traditional non-technology based Intermediate Algebra class was much lower than the other two groups. Chi-square test results revealed that the grade distributions of the non-technology based and technology based Intermediate Algebra courses were not different but there was a significant difference in the grade distribution of the group of students who did not take a developmental algebra course. The researchers concluded that the introduction of CAS technology in developmental courses was a considerable success. They concluded that the availability of CAS gave students who required a developmental course the skills necessary to perform as well as the students who did not.

The results of these studies give educators mixed results upon which to base their instructional decisions regarding CAS. Some studies reported that CAS positively impacted students' achievement (Vlachos & Kehagias, 2000; Shaw et al., 1997). The authors of one study stated, however, that students receiving CAS-based instruction actually scored lower than students who did not receive CAS-based instruction (Hong et al., 2000). In that same study, students also reported mixed attitudes about the use of CAS. Further research on the use of CAS is needed as mathematics educators continue the debate over whether to allow CAS in the classroom.

Summary

As Artigue (2002) pointed out in a personal reflection about research concerning CAS, the value of an instrument that performs procedures must be considered and used appropriately in instruction. Research presented in this section has shown a significant relationship between mathematics achievement and the use of technological tools. These tools also had a positive impact on student attitudes in the mathematics classroom. The following section contains current research specific to digital pen technology.

Current Research Involving Smart Pen Technology

The recent release of the smart pen for commercial use has given researchers little time to produce research regarding its use. A review of the literature revealed two studies involving smart pen technology in educational settings. Another study was found involving the use of the smart pen in the healthcare industry. These studies will be described in the following paragraphs.

In a study funded by the Defense Advanced Research Projects Agency, researchers investigated the effects of smart pen technology on students' cognitive load, referring to the available mental resources one has during the problem-solving process (Oviatt, 2006). The purpose of the study was to investigate the effect of technology on the user to determine if the technology in fact improved cognitive work load and performance. The study sample included twenty high-school students who were classified as either high or low performing. These students were given three non-computational geometry problems. Students were asked to perform each of the three tasks using paper and pencil, the smart pen system, and a graphical tablet interface with keyboard, mouse, and stylus. Students wore headsets with microphone capabilities to record their thought processes. The study found that students experienced greater cognitive work load and performance deterioration as the instruments departed from the traditional work instruments of paper and pencil. Students were faster and experienced less interface distraction with paper and pencil, followed by the smart pen, and the graphical tablet, respectively. From these findings, the researchers concluded that human-centered design which focuses on the effect of instruments on a person's cognitive work load should be a consideration in the innovation of effective technological tools, such as smart pen technology.

An international study analyzed the effects of an instructional program featuring graphics, audio, animation, and hands-on practice on the achievement of 41 Taiwanese second graders (Lee, Shen, & Lee, 2008). To develop and present this multimedia instructional program, instructors utilized computer software, sound equipment, digital boards, and smart pen technology. The researchers of this study conjectured that this combination of multimedia instruction would result in students making fewer errors, such as forgetting strokes and word meanings and making fewer errors with phonetic symbols. In the treatment group, students received multimedia instruction utilizing these technological tools, including the smart pen. In the control group, students received only traditional lecture-style presentations. Students were given a pretest, immediate posttest, and delayed posttest.

The immediate posttest showed that the treatment group performed significantly better than the control group (Lee et al., 2008). The delayed posttest showed that the treatment group performed significantly better in all but one area, complicated words recall and recognition. These results provided evidence that an instructional program including the smart pen has a positive effect on students' performance. It should be noted that these findings are the result of an instructional program featuring many technological tools and cannot be solely attributed to the use of the smart pen.

Smart pen technology also has been used in areas outside education, such as healthcare. A Swedish study examined caregivers' experiences using smart pen technology in frequent pain assessment (Lind, Karlsson, & Fridlund, 2007). Purposeful sampling was utilized to select informants who were medical caretakers with varying backgrounds and levels of education. In the study, patients in a home health care environment used smart pen technology to record an evaluation of their pain and the effects of current treatments. The medical caretakers used these records to evaluate treatments and make adjustments to patient care. The researchers then interviewed these caretakers and analyzed the resulting data. This qualitative study concluded that smart pen technology had a positive influence on patient care by causing caretakers to have a positive outlook on their ability to assess patients' pain. Patients also benefitted by increased participation in their treatment and improved monitoring of pain level fluctuations.

Summary

The smart pen has been shown to produce positive results in educational settings and others, such as healthcare. When compared to traditional lecture-style delivery methods, an instructional program utilizing the smart pen resulted in greater student performance. Another study, however, found that when compared with traditional work instruments, the use of smart pen technology increased students' cognitive work load which resulted in a deterioration of students' performance. In the area of healthcare, the recording of pain diaries using smart pen technology resulted in better treatment for patients. The results of these studies are a catalyst for discussion of the effectiveness of smart pen technology in the mathematics classroom.

Chapter Summary

Many organizations have set forth a standard for the use of technology in the mathematics classroom (AMTE, 2006; ISTE, 2008; NCTM, 2000). While many organizations encourage the use of technology in the classroom, some organizations, however, still denote an absence of research regarding its effectiveness (NMAP, 2008). Research on many technological tools, namely the calculator, dynamic geometry software, and computer algebra systems, has suggested that technology can improve student achievement. Current research on smart pen technology, however, has been limited. In areas outside mathematics education, smart pen technology has shown positive results. Research is needed, however, to determine the impact of smart pen technology in the mathematics classroom.

CHAPTER III: METHODOLOGY

Introduction

In the preface to *Research on Technology and the Teaching and Learning of Mathematics: Volume I,* Heid and Blume (2008) stated, "The stage has been set for the systematic examination of the impact of technology on the teaching and learning of mathematics" (p. vii). This call to action echoes other organizations who express the need for high-quality research on which to base instructional recommendations. This study responded to that call by providing sound methodology which examined the use of the smart pen as an instructional tool in the mathematics classroom.

This chapter addresses the research hypotheses and questions explored. In addition, it contains descriptions of the sample, the instrumentation employed for data collection, the procedures used for conducting the study, and the methods used for data analysis. Finally, the limitations and delimitations of the study are provided along with a chapter summary.

Research Questions and Hypotheses

The purpose of this mixed-methods, quasi-experimental study was to determine the impact of instructional use of the smart pen on students' mathematics achievement and their attitudes toward mathematics. The research questions explored were the following:

1. Do achievement scores of College Algebra students in a community college setting whose instructor utilizes smart pen technology differ significantly from similar students whose instructor does not utilize smart pen technology?

2. Is there a significant difference in the frequency of student views of online course notes between class sections with and without smart pen documents available?
3. What attitudes are characteristic of classrooms with and without instructor's use of the digital pen?

The first two research questions were used to formulate the following hypotheses.

Hypotheses

*Hypothesis 1.*There will be no significant difference in mean mathematics achievement scores by instructor's use of the smart pen as an instructional aid when controlling for pretest scores.

Hypothesis 2. There will be no significant difference in the distribution of student views of online course notes by the existence of smart pen documents for instructional use.

Sample

The sample consisted of two intact classes of mathematics students enrolled in College Algebra at a rural community college in Mississippi. For the fall of 2009, this community college had a student body of 3,707 students with 41% male and 59% female. Among this student body, 78% considered themselves Caucasian, 18% African-American, and 1% Hispanic. The average ACT (formerly known as American College Testing) score for entering freshmen at this school was 18.

To be admitted into College Algebra, students must meet certain prerequisites. First, students are required to have completed Algebra I and II in high school. In addition, they must have made at least a 19 for their ACT mathematics subscore. If students are not able to achieve this score, they have two alternate forms of placement. They may either take a placement test and achieve a predetermined score or successfully complete a developmental algebra course.

Once these prerequisites are met, students register for their College Algebra course through an advisor or on their own initiative. Students enrolled in one of two sections of College Algebra during the fall semester of 2010 were invited to participate in this study. These two sections were selected for their similar characteristics in that both classes had meetings that occurred three times a week for 50-minute intervals and both were taught by the same instructor. It should be noted that students in both groups were not aware of the study at the time of registration.

Hypothesis 1 required the collection of pretest and posttest data from students in both classes. For the analysis of hypothesis 1, the control group consisted of 25 students for whom pretest and posttest data were recorded. According to the instructor's observations, this group consisted of 48% female and 52% male students with 80% Caucasian, 12% African-American, 4% Hispanic, and 4% Asian. The treatment group contained 29 students for whom pretest and posttest data were recorded. According to the instructor's observations, this group consisted of 66% female and 34% male students with 93% Caucasian and 7% African-American.

Due to absenteeism, the sample for hypothesis 1 differed slightly from the sample used for hypothesis 2. For the analysis of hypothesis 2, the online communication platform was used to track the number of student views for each online document posted by the instructor. Any student who was enrolled in the course between September 22, 2010 and October 4, 2010 had access to these online documents. From the study start date to the study end date, there were 40 students enrolled in the control group. Of these 40 students, 50% were males and 50% were females with the exact same percentages of ethnicities represented as the sample used for hypothesis 1. In the treatment group, 41 students were enrolled in the course from the study start date to the study end date. Of these 41 students, 66% were females and 34% were males with the exact same percentages of ethnicities represented as the sample for hypothesis 1.

Instrumentation

To evaluate students' mathematics achievement, students completed a pretest and posttest. In order to have validity, both the pretest and posttest items were selected from two different forms of chapter exams published by the textbook company to accompany the instructional unit presented in class. In communication with an editor from the textbook company, the researcher was informed that the chapter exams used in this study were developed by a subject matter expert who analyzed the material covered in the textbook pages and used the textbook author's overall style to design an assessment that would appropriately test skills presented in the chapter (S. Beeck, personal communication, August 26, 2010). In addition, another subject matter expert was hired to review accuracy.

The items selected from these chapter tests were then reviewed by three instructors at the community college who at the time were preparing to present the same unit of instruction as the one featured in this study. The instructors agreed that the selected items were an appropriate assessment of the objectives presented in the unit. These tests will be referred to as Mathematics Achievement Test-Form A and Mathematics Achievement Test-Form B. Each test contained 14 multiple-choice questions selected from problems designed to evaluate the learning objectives from the material presented in class. These tests can be found in Appendix A and B.

To track student access to digital pen documents, the community college's online communication platform counted the frequency of students' access to digital documents posted by the instructor of the course. This platform featured a tracking tool which could be used for counting the number of student views for digital documents. For the control group, the instructor posted visual-only documents while the treatment group received access to smart pen documents with both audio and visual capabilities. Students could access these files from any location with internet access. This tracking tool measured the frequency of student views for each document available to both the control and treatment group.

For the qualitative portion of the study, students from each class volunteered to be interviewed regarding their opinions of the instructor's use of the smart pen. The interview protocol is provided in Appendix C. This protocol included broad, open-ended questions which addressed student attitudes concerning the subject of mathematics and their self-efficacy in performing mathematical operations. These questions were developed by the researcher to focus students' responses as they related to smart pen technology.

The researcher also served as an instrument. The researcher completed a Bachelor of Arts degree in mathematics in 2004 and a Master of Science degree in mathematics in 2006 from Mississippi State University and has been an instructor at the participating institution for five years. She has also been enrolled as a student in the doctoral program at the University of Mississippi for four years. As a student in the doctoral program, the researcher has completed required coursework pertaining to qualitative research practices.

Procedures

The researcher obtained permission from the mathematics division head to perform this study at the community college. Following this approval, the researcher defended the prospectus and submitted the necessary information to obtain IRB approval. Having previously identified the two sections of College Algebra for this study, the instructor randomly selected one section to serve as the control group and one as the treatment group. Prior to administering the pretest, the researcher disseminated consent forms to the students in participating classes. This consent form can be found in Appendix D. In the next class meeting, the participants completed the Mathematics Achievement Test-Form A to serve as a pretest evaluating students' prior knowledge.

Following the administration of the pretest, the instructor presented the third unit of instruction to participants. This unit, which occurred between September 22, 2010 and October 4, 2010, was chosen to minimize limitations. This choice of unit allowed students time to become familiar with the college's online communication platform yet reduced the risk of discussion among students between both groups which might create treatment diffusion among the participants. The timing of this unit also allowed the study to occur prior to the date allowing student withdrawal from the course.

The instructor had 10 years of teaching experience in both secondary and higher education. In addition, the instructor was experienced in the use of the smart pen as an instructional aid, having used the tool in two previous semesters. She had presented her experience using smart pen technology in many settings, including instructional technology conferences.

Both the control and treatment groups received the same in-class instruction based on notes and examples from the textbook. Prior to the study start date, neither of the groups had access to online documents with the smart pen technology. The treatment group, however, did receive an in-class demonstration of smart pen capabilities at the beginning of the semester.

During the study, the instructor used the digital pen as an instructional aid in the treatment group. Lectures and additional examples were pre-recorded and posted electronically for students to access as the unit of instruction progressed. The files posted to the treatment group had both the visual and audio capabilities of smart pen technology. The experience of the smart pen document afforded students in the treatment group with a very different experience than students in the control group. When a student from the treatment group opened a smart pen document, they were able to see the instructor's pen movements along with the accompanying audio provided by the instructor. The instructor supplied a step-by-step audio dialogue to accompany each of the supplemental exercises she provided in these documents. The experience was very similar to watching a video where the instructor presents an example and gives a step-by-step explanation.

Students in the control group, however, received digital online documents with the same content but without video or audio capabilities. These documents were static and simply appeared much a like a page of notes from a notebook. Maintaining this distinction between the two groups helped to attribute any significant findings to the capabilities of the smart pen and the characteristics of the documents produced by this tool. Both groups were able to access the documents via an online communication platform throughout the unit of instruction.

After receiving instruction, students completed the Mathematics Achievement Test-Form B to serve as a post-test. Due to a copy error which excluded a graph from the post-test, one question had to be eliminated from the original test document. Therefore the corresponding question was also eliminated from the pretest. Students from each section volunteered for interviews by checking a box at the end of Mathematics Achievement Test-Form B indicating that they were interested in being interviewed about their experiences in this classroom. Five students from the treatment group volunteered and participated in interviews. In the control group, six students volunteered to participate in interviews. As the researcher had planned to interview only five individuals, the researcher had to decide which of the six volunteers would not be interviewed. Of the six volunteers, two did not have pretest data recorded due to absenteeism. One of these two students was a former student of the researcher. In order to minimize bias, the researcher made the decision to not interview the student who did not have pretest data and with whom she had had previous contact. Interviews occurred outside of class times at the participants' convenience and were audio recorded. The interviews took place within two weeks of the posttest administration. Using the contact information provided by the student, the researcher contacted each student by phone and scheduled an interview time at the convenience of the student. Students were instructed to meet at the researcher's office at the appointed time.

To control noise and interference, the interviews took place in the researcher's office. The students were assured that their responses would be kept confidential. The students seemed unfamiliar with voicing their feelings about mathematics but quickly relaxed as the interview progressed. The researcher was also familiar with four of the interviewees as former students and they seemed the most at ease. The interviewees gave short, direct responses. The analysis of the data collected with these procedures will be discussed in the following section.

Data Analysis

To evaluate the first hypothesis, a pretest-posttest control-group design was utilized. Mathematics Achievement Test-Form A served as a covariate, ensuring that any significant difference observed between the two groups would be the result of the treatment. Both the pretest and posttest were scored using a scantron grading system. The number of correct answers served as the score. Data was entered by the researcher into a spreadsheet software program and double-checked for accuracy. This information was imported into the statistical analysis software. All statistical tests were checked both electronically and manually to ensure accuracy. The Levene's Test of Equality of Error Variances and the test of between-subjects effects were utilized to validate the assumptions necessary for an ANCOVA test. The pretest and posttest scores for the two classes were then analyzed using the ANCOVA test.

The second hypothesis was investigated using the tracking feature in the school's online communication platform. The frequency of student access to digital course notes via the online communication platform for both the treatment and control groups was counted and compared using a one-way chi-square test. That data was used to determine if there was a significant difference in the frequency of student access to online course notes between the treatment and control group.

The third research question was evaluated using qualitative methods. According to Gall, Gall, and Borg (2007), phenomenological research seeks to understand how reality appears to individuals. This study used student interviews to investigate how smart pen technology impacted students' experiences in the mathematics classroom. The interviews conducted with students were transcribed verbatim. Using open coding, then the researcher analyzed the interviews for trends and commonalities among students' perceptions about mathematics, their self-efficacy, and the instructor's use of smart pen technology. The researcher read through each interview thoroughly and made notes of any commonalities among responses. The questions were then separated individually and responses among the two groups analyzed per question to determine if there were any trends among responses.

Limitations and Delimitations

The relative small scale of the study and the lack of randomly selected participants served as limitations to the generalizability of the study. The instructional methods and mathematics achievement tests focused on procedural skills. Therefore, another limitation of the study was its inability to evaluate other aspects of mathematical proficiency, such as conceptual understanding. According to item response theory, the nature of the multiple choice examination also served as a limitation (Baker, 2001). The researcher's role as an instrument introduced a bias to the study. Prior to beginning each interview, the students were assured that their responses would be confidential and that their instructor would not be able to identify their responses. The study also presumed that students truthfully answered the researcher during the interview process.

Chapter Summary

In summary, this chapter defined the research questions and hypotheses that were investigated as well as the sample and population for the study. The instrumentation and procedures for collection of data were presented. The methods for data analysis and limitations and delimitations were also provided. The chapters that follow will address the findings of these analyses and their implications.

CHAPTER IV: RESULTS

Introduction

International comparisons have shown the need for improvement in U.S. mathematics education (NCES, 2009). In an effort to improve students' mathematics achievement, educators have implemented new technology into the mathematics classroom. While research has shown that many other technological devices have not hindered students' mathematics achievement, there is an absence of research regarding the use of smart pen technology in the mathematics classroom.

The purpose of this mixed-methods study was to examine the effects of smart pen technology on the achievement and attitudes of community college students enrolled in a College Algebra course. This chapter reports the analysis for the procedures outlined in Chapter III and is organized into two sections. The first section provides the results of quantitative methods used to evaluate hypotheses 1 and 2. These hypotheses examined the effect of smart pen technology on students' mathematics achievement and the frequency of students' views of online documents. The second section presents results of qualitative methods used to explore research question 3. This research question examined student attitudes regarding the subject of mathematics and the instructor's use of smart pen technology.

Quantitative Analyses

The first two research questions in this study investigated the effect of the instructor's use of smart pen technology on students' mathematics achievement and students' use of available online documents. Quantitative methods were employed to examine each of these research questions using the appropriate statistical test. All quantitative tests were evaluated with a 95% confidence interval using the Statistical Package for the Social Sciences (SPSS).The following sections report the results of the analysis of each null hypothesis formed by the first two research questions.

Hypothesis 1. There will be no significant difference in mean mathematics achievement scores by instructor's use of the smart pen as an instructional aid when controlling for pretest scores.

Prior to the analysis of covariance (ANCOVA), the Levene's Test of Equality of Error Variances produced a significance value $p = .759$, which satisfied the assumption for homogeneity of variance. Using the tests of between-subjects effects, the relationship between the dependent variable and covariate yielded $F = 20.722$ with significance $p = .000$, which indicated that there was sufficient evidence of a linear relationship between the dependent variable (posttest scores) and covariate (pretest scores). This satisfied the assumption of a linear relationship between the covariate and dependent variable.

An ANCOVA test was used to analyze this hypothesis with the posttest achievement score serving as the dependent variable, the group serving as the independent variable, and the pretest achievement score serving as the covariate. As demonstrated in Table 1, the ANCOVA yielded $F(1,51) = .524$ with significance $p = .472$.

Table 1

ANCOVA: Mathematics Achievement Test Scores

Source	*SS*	*df*	*MS*	*F*	*p*
Covariate	70.990	1	70.990	20.722	.000
Between	1.796	1	1.796	.524	.472
Within	174.714	51	3.426		
Total	247.5	53			

These results indicated there was not a significant difference in mean mathematics achievement scores by instructor's use of the smart pen as an instructional aid when controlling for pretest scores. Therefore, hypothesis 1 failed to be rejected.

Hypothesis 2. There will be no significant difference in the distribution of student views of online course notes by the existence of smart pen documents for instructional use.

To examine this hypothesis, the number of student views collected from the online tracking system was analyzed using a one-way chi-square test. In total, there were 105 views conducted by students from the control group and 128 views conducted by students from the treatment group. As demonstrated in Table 2, this data produced $\chi^2(233) = 2.270$ with significance $p = .132$.

Table 2

Frequencies of Student Access

Group	Observed N	Expected N	Residual
Control	105	116.5	-11.5
Treatment	128	116.5	11.5
Total	233		

These results indicated there was not a significant difference in the distribution of student views of online course notes by the existence of smart pen documents for instructional use. Therefore, hypothesis 2 failed to be rejected

Summary of Quantitative Findings

Quantitative methods were used to investigate the first two research questions regarding the effect of smart pen technology on students' mathematics achievement and students' use of available online course notes. Results from the ANCOVA test indicated there was not a significant difference in mean mathematics achievement scores by instructor's use of the smart pen as an instructional aid when controlling for pretest scores. Results from the chi-square test indicated that there was not a significant difference in the distribution of student views of online course notes by the existence of smart pen documents for instructional use.

Qualitative Analysis

One of the goals of phenomenological research is to recognize how reality appears to participants who have experienced the phenomena (Gall et al., 2007). This type of research was utilized in this study to explore the effects of the use of smart pen technology on attitudes of community college students enrolled in a College Algebra course. The third research question in the study was as follows: What attitudes are characteristic of students in classrooms with and without instructor's use of the smart pen?

Five participants from each group were interviewed about their attitudes and experiences in the College Algebra course in which they were currently enrolled. Specifically, the interview included questions regarding participants' attitudes toward the subject of mathematics, their mathematics self-efficacy, the instructor's use of resources, and suggestions for increasing understanding. Open coding was used to analyze participant responses. This section is organized according to responses from both the treatment group and control group. Participants' real names have been replaced with pseudonyms.

Treatment Group

The five participants interviewed from the treatment group were Lindsey, Ginger, Pam, Valerie, and Rachel. The first interview questions asked participants about their feelings regarding the subject of mathematics and if that feeling had changed since beginning the course. Four out of five participants in the treatment group responded that they liked or loved the subject of mathematics. Lindsey stated, "Um, I like it. It seems easy because there's like a definite answer." Pam replied, "Mathematics as a whole is not really great but algebra itself, I love it." Only one of the five interviewees, Valerie, responded that they did not like the subject stating, "Truthfully, I really just don't like math, but I'm really good at it."

The majority of participants did not seem to feel that the course in which they were enrolled affected their attitude toward the subject of mathematics. When asked about whether their opinion about the subject of mathematics had changed since they began this course, three out of five participants responded they had always held that opinion. Two participants responded that their opinion had improved since the course began. After responding that she loved algebra and asked if this attitude had changed since she began her current mathematics course or if she had always held that opinion, Pam responded, “Not always, but I do like it a lot more now than I used to.”

All five participants from the treatment group gave positive responses about their ability to do mathematics. All participants reported that they were “good” or “pretty good” at performing mathematics. Lindsey stated, “I think I’m pretty good at math. It’s not always my best subject but it’s not that, like, bad to do. (laughs) It’s not like painful or anything.” Ginger simply replied, “I think I’m good at it. I’ve always had A’s.” The other three student responses included the phrase “pretty good.”

The interviewer then questioned participants if their ability to perform mathematics had changed since they began the course. Similar to the responses concerning attitude, three participants had always felt confident about their ability to do mathematics. Two participants felt their ability had improved since beginning this course. Pam stated, “I think I understand it better. Like, the basic concepts.”

Next, the researcher questioned participants about their instructor’s use of resources. Responses centered on the instructor’s use of technology in the course. Every participant in the treatment group initiated a response that involved a technological tool. Of those five responses, three participants initiated a reply that mentioned the instructor’s use of the smart pen. Ginger replied, “I like the, um, I don’t know what it’s called there’s a thing she uses with a pen. I mean it’s like a [computerized blackboard] but it’s not a [computerized blackboard].”

After responding that she was intrigued by the smart pen, Pam commented, “It was really helpful because they explain it step-by-step.” Similarly, Rachel remarked about the smart pen, “If I get confused on a problem, I’ll watch that and it works. That helps me out a lot.” Of the two remaining participants that did not initiate a response involving the smart pen, Ginger stated that she did go online and look at the smart pen documents. Lindsey stated that she did not view any documents.

The researcher then asked participants how often they viewed the smart pen documents. Valerie stated, “Those things are pretty neat. I get on there sometimes and look if I can’t understand. If I forgot how she did a problem, I’ll go back and like relook at it. And it’s pretty easy.” When asked how often she looked at the smart pen documents, Rachel replied, “Probably just about every time I do my homework. If I have one that gives me trouble, I always look at it.” Ginger reported, “Maybe once or twice, like every other week, as I got ready for tests or as I did homework and stuff. Not every week, but a lot.” In response to how often she used the documents, Pam stated the following:

> Well, I’ve only looked at it once and that was really just to show my mama because I was so excited about it. But it’s a lot like the [online homework] when you click the [video feature] for it to explain it to you. It’s a lot like that.

The final questions of the interview asked participants if they took this class again, would they have any suggestions that might increase their understanding of the material. Four participants from this group indicated that they were satisfied with the course. No participants made suggestions regarding smart pen technology or any other technological tool. Four participants from the treatment group replied that the class was “good” or that they had no such suggestions. Only one participant, Rachel, made a suggestion that might improve her understanding and it regarded the need for more explicit directions on the in-class exams.

Summary of Findings from Treatment Group

When questioned about their attitude towards mathematics, the majority of the five interview participants responded that they liked the subject of mathematics. In addition, all five participants felt positive about their ability to do mathematics. In both cases, however, most participants did not attribute this attitude or their ability to do mathematics to the course in which they were enrolled.

Every participant in this group responded that a technological tool used in the classroom interested or intrigued them. Of those responses, three participants initiated a response that included the online documents with smart pen technology. Four out of the five students responded that they did view the smart pen documents. Most participants from this group responded that they viewed the documents during the time they did their homework or in preparation for the test in an effort to improve achievement. Thus despite the failure to reject hypothesis 1 regarding participants' mathematics achievement, participants' continued use of the technology leads one to believe that they perceived it as useful.

Participants from this group also seemed to be satisfied with their understanding in the course. When asked if they could make any suggestions to increase understanding if they took the course again, most participants stated they could make no suggestions. Only one participant made a suggestion and that involved the need for more explicit directions on in-class tests. Table 3 summarizes the responses given by participants from the treatment group.

Table 3

Summary of Qualitative Findings from Treatment Group

Participant	Like Math	Attitude Changed	Ability To Do Math	Ability Changed	Resource Included Technology	Viewed Online Documents	Made Suggestion for Understanding
Lindsey	Y	N	Y	N	Y	N	N
Ginger	Y	N	Y	N	Y	Y	N
Pam	Y	Y	Y	Y	Y	Y	N
Valerie	N	Y	Y	N	Y	Y	N
Rachel	Y	N	Y	Y	Y	Y	Y

Note. Participant responses have been categorized for each question and are designated Y = Yes and N = No.

Control Group

The five participants interviewed in the control group were Matthew, Janessa, John, Shikha, and Dustin. Using the same interview protocol, the researcher first questioned participants about their attitude toward the subject of mathematics. Three participants stated that they liked the subject of mathematics. One participant, Shikha, replied, "Well, I kind of like it. It comes easy to me. It's natural kind of. I can learn it really fast. And I don't really study for my tests." John responded, "It's good for most cases, but it's very confusing. Just because there are a lot of numbers involved, depending on where you go with math."

Two participants from the control group gave a clear response that their difficulty performing mathematical procedures affected their attitude towards mathematics. When asked about how he felt toward mathematics, Matthew replied the following:

> It's so hard. (laughs) It is difficult. It does not click with me very well. And it just takes me a little bit longer to absorb the information. Most people just get it one time and they're done. I don't. It takes me forever.

In response to the same question, Janessa said that she had never liked mathematics and that she was not good at performing mathematics; however, since starting college her enrollment in developmental courses had improved her performance and her attitude toward mathematics.

The researcher then questioned each participant regarding if they felt their attitude had changed since they began the course. Similar to the treatment group, three out of five participants responded that their attitude toward mathematics had not changed since the course began. The other two participants indicated there had been an improvement in their attitude toward the subject of mathematics. In response to whether her attitude had changed since she started her current mathematics course, Janessa stated the following:

> Well, I've never really liked math. But I had you in the beginning [referring to the interviewer as the instructor for the student's developmental courses] so I actually got to learn because I actually didn't learn that much in high school. So I've actually got to go through and learn it all. So I'm getting it. I like it a little bit better.

The other student, Dustin, responded, "Well, it definitely has come to a new approach and this has changed my perspective on looking at mathematics more objectively now."

Participants were then questioned about their ability to perform mathematics. Two participants from the control group gave a negative reply. Matthew stated, "It's frustrating. Because I'm a physical education major and it doesn't make much sense as to why I have to know the quadrant of something, or anything like that." Janessa stated, "It's not that great. (laughs) Yeah, it's not that great. I'm not gonna major in that." Two more participants from the group gave a moderate response. John reported that he felt his ability was slightly above average, describing it as five and a half on a scale of ten. In reference to his skills, Dustin responded, “Still lacking, but improving.” Shikha was the only participant from this group who self-described her ability as adequate, stating, “I think I feel okay. I mean word problems are hectic for me. But I’m okay with it, I can do pretty good.”

When questioned if their ability to perform mathematics had changed since they started the course, four participants indicated they had always felt that way. The only student who had reported that their ability to do mathematics had improved was John, who had initially indicated that he was not confident in his ability in the beginning. In response to whether he felt his ability had changed since he began the class, he stated “Well it has slightly. It’s gotten better, I’ve progressed. That’s the best I can say about it.” Thus most participants felt their ability to perform mathematics was not impacted by the course in which they were currently enrolled.

The next interview questions regarded the instructor’s use of resources. Participants’ responses included various classroom tools other than the online documents. Similar to the interview process of the treatment group, if the student’s response did not include remarks about the posted online documents, the student was then prompted by the interviewer about their utilization of the documents.

Only two participants initiated a response that a technological tool used in the classroom interested or intrigued them. Of these two responses, only one involved the online course notes. Janessa replied, “Um, she does the notes, the notes online, or whatever.” The other response centered on the use of the digital projection device used by the instructor during classroom lectures to both groups. One recurring subject from control group responses to this question was the participants’ focus on the instructor. The three remaining responses seemed to focus on some aspect of the instructor's personal nature, her teaching style, helpful attitude, or jovial personality.

The researcher then questioned participants concerning how often they viewed the online documents. Of the three participants from the control group that stated they did view the online documents, two reported they used them to complete their in-class note taking. Matthew reported the following:

> I look at them. And those do help, when I see the way she works the problem in class. We're writing, and writing, and we're trying to get to the next problem because we only have the time period. When I go back and look at it, I try to go step by step slowly until I understand it.

Similarly, Janessa stated the following:

> I'll sometimes go and check. Which I take notes in class, I do exactly like what she does. That way I can go through and look and if I need to, I get on the internet and look at it if I missed anything.

John reported that while he did go online and view the documents, they were not helpful because they did not seem to match the notes. Of the two participants who did not view the documents, Shikha stated she did not go online and view any of the documents because she was in class and able to get all the notes. Student responses from the control group seemed to focus on the documents as assistance for note-taking.

The final questions of the interview asked participants if they were to take this course again, would they have any suggestions that might increase their understanding. Responses from participants in the control group indicated that they were dissatisfied with their understanding in the course. All five participants in this group made a suggestion that they felt would improve their understanding. All suggestions were improvements the student, rather than the instructor, could do to improve their performance. One student, who was repeating the course, stated the following:

> This year, I've moved to the front, in front of her. And that's helped me a lot to understand it because I'm closer to her. And I pay more attention to her because I can't fall asleep in front of the class. That can help. But I'm actually doing the work, like the [online homework], and the extra homework out of the book that is not required is a big help.

Another student who was repeating the course gave a similar response, "Well, probably paying attention. Which, this year, I paid attention a lot more. That was probably my problem before. But I pay a lot more attention." Other participants' suggestions involved taking the time to practice more or taking practice tests before the unit of instruction. One student reported that she would take more notes accurately.

Summary of Findings from Control Group

Three participants from the control group stated that they liked the subject of mathematics; however, two participants stated they did not like the subject of mathematics. In response to the same question, most students included a statement regarding their ability to do mathematics in their response. Only one participant responded that her ability was adequate. Other participants responded that their ability was moderate or gave a negative response to their ability to do mathematics. Similar to the treatment group, most students did not attribute their attitude toward mathematics or their ability to do mathematics to the course in which they were enrolled.

When asked if any of the instructor's resources particularly interested or intrigued them, the majority of participants focused on the instructor's personality rather than technological resources. Only two participant responses' included a technological tool used in the classroom. While most participants did go online and view the documents, participants seemed to utilize the online documents strictly as a resource for completing the notes taken in class.

Participants from the control group seemed dissatisfied with their understanding in the class. All five participants made suggestions for improving understanding. Their suggestions, however, focused on study habits that the participant could employ that would lead to greater understanding, rather than any change in resources from the instructor. Table 4 is a summary of student responses.

Table 4

Summary of Qualitative Findings from Control Group

Participant	Like Math	Attitude Changed	Ability To Do Math	Ability Changed	Resource Included Technology	Viewed Online Documents	Made Suggestion for Understanding
Matthew	N	N	N	N	N	Y	Y
Janessa	N	Y	N	N	Y	Y	Y
John	Y	N	Y	Y	N	Y	Y
Shikha	Y	N	Y	N	Y	N	Y
Dustin	Y	Y	Y/N	Y	N	N	Y

Note. Participant responses have been categorized for each question and are designated Y = Yes and N = No.

Summary of Qualitative Findings

In summary, many participants' responses regarding their attitudes toward mathematics included a statement about their ability to perform mathematics. The majority of participants in both groups did not attribute their attitude toward mathematics or their ability to perform mathematics to the course in which they were enrolled. There were participants present in each group, however, who did feel that their attitude towards mathematics and ability to perform mathematics improved since they began the course.

Participants from the treatment group appeared to focus more on their instructor's use of technology in the classroom as a resource than participants from the control group. Participants from the control group appeared to focus more on the instructor's personal teaching style rather than technological tools used in the classroom. There also seemed to be a distinct difference in the way participants from each group employed the online documents. When questioned about their use of online documents, participants from the treatment group used the online documents as an aid for completing homework and test preparation. Participants from the control group focused on the online documents as a supplement to in-class note-taking.

Participants from the treatment group seemed to be more satisfied with their understanding gained in this mathematics classroom than participants from the control group. Given the opportunity to take the course again, every student from the control group made a suggestion for improving his or her understanding in contrast with only one student from the treatment group. Participants from the control group focused more on their personal study habits as the key to improving understanding rather than resources provided by the instructor, such as online course notes.

Chapter Summary

The results from the quantitative analysis of hypothesis 1 showed that the instructor's use of smart pen technology did not affect participants' mathematics achievement. The results from analysis of hypothesis 2 revealed that there was not a significant difference in the distribution of student views of online course notes by the existence of smart pen documents for instructional use. The third research question was investigated by qualitative methods. According to responses from student interviews, participants from the treatment group seemed to focus more on the instructor's use of technology than participants from the control group. Participants from each group also seemed to utilize the online documents in different capacities. The majority of participants from the treatment group employed the documents as an aid for completing homework and preparing for in-class tests. In contrast, participants from the control group seemed to focus on the documents as aids for completing in-class notes. Responses also indicated that participants from the treatment group seemed more satisfied with their level of understanding achieved in the course than participants from the control group. In the following chapter, recommendations and implications for the study will be discussed.

CHAPTER V: SUMMARY, DISCUSSION, AND RECOMMENDATIONS

Introduction

The current state of mathematics education has given educators cause to seek technology which may be used in the mathematics classroom to improve student performance (NCES, 2009). Studies have shown a positive relationship between the use of technology and student attitudes in the classroom and a connection between student attitudes and achievement in the mathematics classroom (Higbee & Thomas 1999; Lee & Chen, 2010). This study employed both qualitative and quantitative methods of research to investigate the effects of a recently released technology, the smart pen, on the achievement and attitudes of community college students enrolled in a College Algebra course. This chapter consists of a summary of the study, discussion of findings, implications of the findings, and recommendations for future research.

Summary of the Study

The purpose of this quasi-experimental, mixed-methods study was to investigate the impact of the instructor's use of smart pen technology on the mathematics achievement and attitudes of College Algebra students in a community college setting. This study utilized a nonequivalent control-group design. The three research questions which guided this study were the following:

1. Do achievement scores of College Algebra students in a community college setting whose instructor utilizes smart pen technology differ significantly from similar students whose instructor does not utilize smart pen technology?

2. Is there a significant difference in the frequency of student views of online course notes between class sections with and without smart pen documents available?
3. What attitudes are characteristic of classrooms with and without instructor's use of the digital pen?

The first two research questions were used to formulate null hypotheses which were analyzed quantitatively. To analyze the first hypothesis, pretest and posttest data were collected from 54 participants to evaluate if smart pen technology had an impact on students' mathematics achievement. The second hypothesis used data collected by the online communication platform to determine how often the 81 students enrolled in both sections accessed online documents posted by the instructor. The third research question was explored using qualitative methods. The researcher interviewed five participants from each group about their attitudes and perceptions regarding mathematics and the mathematics course in which they were enrolled. Their responses were analyzed using open coding to determine if there were any trends or commonalities among responses.

Discussion of Findings

To evaluate hypothesis 1, pretest and posttest data from participants in both groups were analyzed using the ANCOVA test. Results showed that there was no significant difference in mean mathematics achievement scores by instructor's use of the smart pen as an instructional aid when controlling for pretest scores. While the results of this study did not show that the instructor's use of smart pen technology improved participants' mathematics achievement, they did not indicate that the instructor's use of smart pen technology was a hindrance to participants' mathematics achievement. These results are aligned with research findings concerning the use of many forms of technology in the mathematics classroom, such as calculators (Ellington, 2006) and computer algebra systems (Hong et al., 2000).

In considering this finding, the lack of significance in participants’ mathematical achievement is not surprising given that both groups received nearly identical instruction. The pen was not used as a primary source of instruction but rather a supplemental resource that was available to students outside of class. In addition, this lack of significance is further explained by participants’ overall failure to utilize the online documents. Data revealed that no single online document was accessed by more than 13 students from any one class. The average number of views per available document was 5.6 for the treatment group and 4.6 for the control group out of approximately 40 registered students per class who had the ability to access the documents.

Although it involved a different technology, similar results were found in a study which analyzed the study habits of college students enrolled in an Intermediate Algebra course at Boise State University (Belcheir, 2002). A survey questioned 734 students about their use of a supplemental video lecture series which was available to students through the library. Although in different formats, this resource shares many characteristics with smart pen technology, such as audio and transmission of symbolic representation capabilities. The use of this resource was also optional. When questioned if they found this resource helpful, 77.5% of students responded “not applicable.” Therefore, students may not perceive voluntary supplemental resources which reiterate instruction presented in the classroom as necessary for improving mathematics achievement. This idea was echoed by a participant during the interview. The participant stated that she did not view the online documents because she received all the notes in class.

This lack of utilization seemed to be characteristic of both groups. To evaluate hypothesis 2, the online communication platform was used to track the number of student views of online documents in both groups. Results of the chi-square test indicated there was no significant difference in the distribution of student views of online course notes by the existence of smart pen documents for instructional use. Therefore, the existence of documents with smart pen capabilities did not increase the perceived usefulness of the resource to the participants.

The third question was investigated by conducting interviews about participants' attitudes toward mathematics and use of the online documents. Recognizing the low numbers of participants who actually utilized the online documents, one must conclude that their responses could not be considered representative of the group. These interviews, however, did reveal similar dispositions among participants from the same group. When contrasted with responses from the control group, responses from participants in the treatment group indicated that the instructor's use of smart pen technology caused participants to focus on technological tools that were being used in the classroom. There was also a distinct difference in how participants from each group utilized the online documents. Participants from the treatment group employed the documents for assistance with completing homework or for test preparation. In contrast, participants from the control group viewed the documents as assistance for completing their in-class notes.

Participants from the treatment group also indicated that they were more satisfied with the level of understanding attained in the course when compared with participants from the control group, who all indicated they had suggestions for improving their understanding. Similar results regarding students' satisfaction were reported by a study which investigated the effects of the presence of an online archival system of video lectures and in-class notes on students' perceived performance in college mathematics courses (Cascaval, Fogler, Abrams, & Durham, 2008). In this study, 51 participants enrolled in mathematics courses with access to online lectures that featured both visual and audio capabilities completed a survey regarding their usage and satisfaction of the online archival system. Results of the study showed that participants with access to an online archival system of video lectures and class notes had improved performance perceptions and overall experience in the class.

Recommendations and Implications

In *A Research Companion to Principles and Standards for School Mathematics*, Hiebert (2003) stated that the best way to draw conclusions concerning issues like the use of calculators in the classroom was to analyze the trends of many studies regarding their use. He also stated that no single study would provide the evidence needed to make a conclusion regarding their use in the classroom. He noted that decisions regarding curriculum and pedagogy were always tentative and subject to change with new information and changing conditions. Similarly, this study did not provide a definitive answer as to whether smart pen technology should be used in the classroom. There are, however, implications from this research that support the following two recommendations.

The first recommendation is that the study should be replicated with larger sample sizes to validate its findings. If future studies provide similar results, the implication would be that educators should give careful consideration before implementation of instructional use of smart pen technology as a tool for increasing student achievement. While this technological tool has many helpful features, such as assisting students with note-taking and providing a means for communication with absentee students, it could not be relied upon to increase students' mathematics achievement as defined in this study.

The second recommendation would be to replicate this study with students enrolled in a course format which required the use of the online documents. Although the vast majority of participants did not utilize the online documents, qualitative findings revealed that most interview participants who did utilize the smart pen documents had a more productive disposition and greater overall satisfaction with their level of understanding attained in the course. If required student utilization confirmed that the instructional use of smart pen technology improved student attitudes and satisfaction with the course, the implication would be increased student engagement in the classroom due to smart pen technology. Research has shown a significant link between student attitudes and achievement in the mathematics classroom (Higbee & Thomas, 1999; Ma & Kishor, 1997; Muis 2004). Therefore, if the qualitative findings were confirmed, there is still a possibility that smart pen technology could improve students' mathematics achievement.

Suggestions for future research would be to modify this study to analyze the relationship between individual student performance and the number of individual student accesses of online documents. These results would provide stronger evidence of the relationship between the instructor's use of smart pen technology and students' mathematics achievement. It should also be noted that the instruction and assessments utilized in this study did not evaluate conceptual understanding. Therefore, conclusions could not be made regarding the relationship between smart pen technology and students' conceptual understanding.

In addition, it should be noted that the current College Algebra course is designed to be a review of many topics taught in students' high school mathematics courses. Therefore, the study should also be replicated with other courses where students are learning new mathematical concepts. Studies in other content areas should also be investigated to determine if the pen has an impact in other disciplines. If studies are conducted that address the aforementioned ideas, the resulting database of research regarding this tool will give educational practitioners a better idea of how smart pen technology would be utilized most effectively in the classroom.

Chapter Summary

The purpose of this study was to investigate the effects of smart pen technology on the mathematics achievement and attitudes of community college students in a College Algebra course. Results of quantitative analysis found that the existence of smart pen documents did not impact students' mathematics achievement. Results also revealed that the existence of smart pen documents did not impact the number of times students accessed online course notes. Results of qualitative analysis, however, indicated several recurring themes which signify the need for future research regarding the impact of smart pen technology.

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List of Appendices

APPENDIX A

Mathematics Achievement Test-Form A

Student ID:___________________ Class CRN:______________________

1. Find the midpoint of the line segment with endpoints $(-2,3)$ and $(-4,-5)$.

(a) $(1,-9)$ (b) $(-1,-4)$ (c) $(1,4)$ (d) $(-3,-1)$ (e) None of these

2. Determine the length of the line segment with endpoints $(-3,-5)$ and $(7,-11)$.

(a) 12 (b) $2\sqrt{34}$ (c) $2\sqrt{13}$ d) $\sqrt{356}$ (e) None of these

3. Determine the x- and y-intercepts of the graph of $x = 3y^2 - 9$.

(a) $(-9,0),(0,3),(0,-3)$ (b) $(-9,0),(0,\sqrt{3}),(0,-\sqrt{3})$

(c) $(0,-9),(\sqrt{3},0),(-\sqrt{3},0)$ (d) $(-9,0)$, no y-intercepts (e) None of these

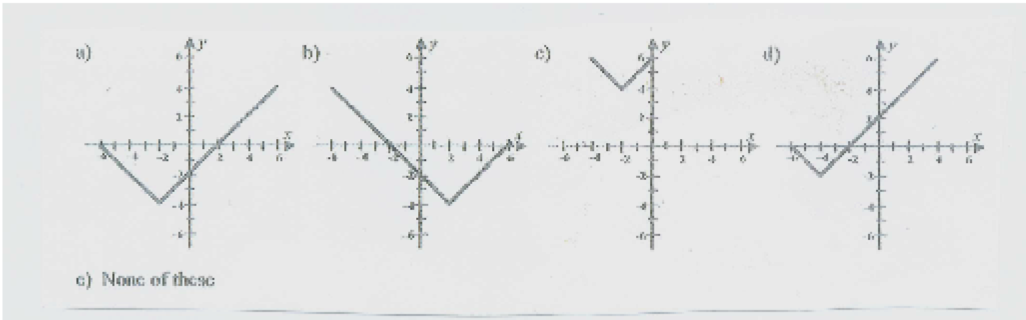
4. Determine the domain of $f(x) = \dfrac{3}{2x-1}$.

(a) $\left\{x \middle| x \neq \frac{1}{2}\right\}$ (b) $\{x | x \neq 2\}$ (c) $\left\{x \middle| x > \frac{1}{2}\right\}$ (d) $\{x | x \neq 3\}$ (e) None of these

5. Determine the domain of the function $f(x) = \sqrt{8-x}$.

(a) $\{x | x \geq 8\}$ (b) $\{x | x > 8\}$ (c) $\{x | x < -8\}$ (d) $\{x | x \leq 8\}$ (e) None of these

6. Which one of the following shows a portion of the graph of $y = |x+2| - 4$?



7. Identify the interval over which $f(x) = |x-4| - |x+5|$ is a constant function.

(a) $(-\infty, -4]$ and $[5, \infty)$ (b) $(-\infty, -5]$ and $[4, \infty)$
(c) $(-\infty, 5]$ (d) $[-5, \infty)$ (e) None of these

8. Determine the symmetries of $y^2 = x$.

(a) symmetric to the x-axis (b) symmetric to the y-axis
(b) symmetric to the origin (d) a,b, and c (e) None of these

9. Find $P(2)$, given that $P(x) = \begin{cases} -x^2 + x + 2 & \text{if } x < 5 \\ x^3 - x - 1 & \text{if } x \geq 5 \end{cases}$

(a) 0 (b) 8 (c) 4 (d) -2 (e) None of these

10. Find the maximum or minimum value of the quadratic function given by
$f(x) = -3(x-1)^2 + 4$.

(a) 4, minimum (b) -4, minimum
(c) 4, maximum (d) -4, maximum (e)None of these

11. A linear function has a slope of 3 and passes through the point $(-4, -6)$. Which of the following is the slope-intercept equation of this line?

(a) $y = 2x + 8$ (b) $y = 2x - 2$
(c) $y = 2x + 2$ (d) $y = \frac{1}{2}x - 8$ (e)None of these

12. Use the method of completing the square to write the quadratic equation $f(x) = -x^2 - 6x - 5$ in standard form.

(a) $f(x) = -(x+3)^2 + 4$ (b) $f(x) = -(x-6)^2 + 31$

(c) $f(x) = -(x-3)^2 + 4$ (d) $f(x) = -(x-6)^2 - 5$ (e) None of these

13. The distance traveled by a ball rolling down a ramp is given by $s(t) = 3.5t^2$, where t is the time in seconds after the ball is released and $s(t)$ is measured in feet. Evaluate the average velocity of the ball over the time interval $[1.0,\ 1.5]$.

(a) 3.5 feet per second (b) 5.45 feet per second (c) 7.25 feet per second

(d) 8.75 feet per second (e) None of these

14. Solve the system: $\begin{cases} 2x + 3y = 6 \\ y = x + 7 \end{cases}$ What is the value of y in the solution?

(a) $y = -4$ (b) $y = 4$ (c) $y = 2$

(d) The system is inconsistent, there is no solution (e)None of these

APPENDIX B

Mathematics Achievement Test-Form B

Student ID:____________________ Class CRN:_______________________

1. Find the midpoint of the line segment with endpoints $(-2,-1)$ and $(3,-5)$.

(a) $(\frac{1}{2},-3)$ (b) $(-\frac{5}{2},-3)$ (c) $(1,-3)$ (d) $(1,-6)$ (e) None of these

2. Determine the length of the line segment with endpoints $(-2,-7)$ and $(-4,5)$.

(a) $2\sqrt{10}$ (b) $4\sqrt{2}$ (c) 14 (d) $2\sqrt{37}$ (e) None of these

3. Determine the x- and y-intercepts of the graph of $x = 2y^2 - 8$.

(a) $(-8,0)$, $(0,-2),(0,2)$ (b) $(-8,0),(0,2i),(0,-2i)$
(c) $(0,-8),(2,0),(-2,0)$ (d) $(-8,0)$, no y-intercepts (e) None of these

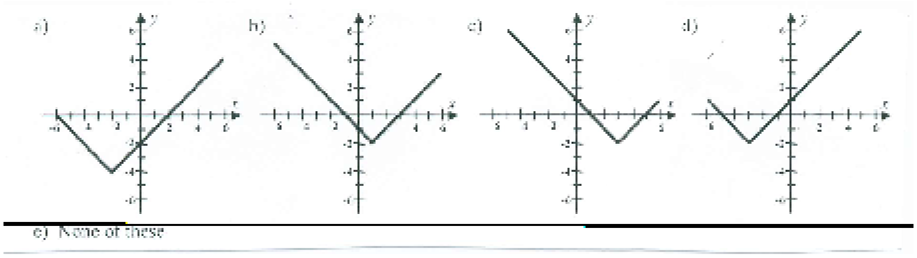
4. Determine the domain of the function $f(x) = \sqrt{6-x}$.

(a) $\{x|x \geq 6\}$ (b) $\{x|x \leq -6\}$ (c) $\{x|x \geq -6\}$
(d) $\{x|x \leq 6\}$ (e) None of these

5. Determine the domain of $f(x) = \frac{3}{2x-1}$.

(a) $\left\{x \middle| x \neq \frac{1}{2}\right\}$ (b) $\{x|x \neq 2\}$ (c) $\left\{x \middle| x > \frac{1}{2}\right\}$ (d) $\{x|x \neq 3\}$ (e) None of these

6. Which one of the following shows a portion of the graph of $y = |x-3| - 2$?



7. Identify the interval over which $f(x) = -3|x-1| + 4$ is a constant function.

(a) $(-\infty, -1]$ (b) $[1, \infty)$
(c) $(-\infty, 1]$ (d) $[-\infty, \infty)$ (e) None of these

8. Determine the symmetries of $x^2 = y^2 + 1$.

(a) symmetric to the x-axis (b) symmetric to the y-axis
(c) symmetric to the origin (d) a,b, and c (e) None of these

9. Find $P(-2)$, given that $P(x) = \begin{cases} -x^2 + x + 2 & \text{if } x < 5 \\ x^3 - x - 1 & \text{if } x \geq 5 \end{cases}$

(a) -4 (b) 4 (c) -7 (d) 8 (e) None of these

10. Find the maximum or minimum value of the quadratic function given by $f(x) = 0.5(x+1)^2 - 2$.

(b) 2, minimum (b) -2, minimum
(c) -2, maximum (d) 2, maximum (e) None of these

11. A linear function has a slope of 3 and passes through the point $(-1, -2)$. Which of the following is the slope-intercept equation of this line?

(a) $y = 3x - 3$ (b) $y = 3x + 3$
(c) $y = 3x + 1$ (d) $y = \frac{1}{3}x + 1$ (e)None of these

12. Use the method of completing the square to write the quadratic equation $f(x) = 2x^2 - 4x - 2$ in standard form.

(a) $f(x) = 2(x-2)^2 - 6$ (b) $f(x) = 2(x-1)^2 - 4$
(c) $f(x) = (2x-1)^2 - 1$ (d) $f(x) = 2(x-1)^2 - 2$ (e) None of these

13. The distance traveled by a ball rolling down a ramp is given by $s(t) = 3t^2$, where t is the time in seconds after the ball is released and $s(t)$ is measured in feet. Evaluate the average velocity of the ball over the time interval $[2.00,\ 2.01]$.

(a) 12 feet per second (b) 12.03 feet per second (c) 12.01 feet per second
(e) 12.05 feet per second (e) None of these

14. Solve the system: $\begin{cases} 2x - 3y = 15 \\ y = \dfrac{2}{3}x - 10 \end{cases}$ What is the value of y in the solution?

(a) $y = -\dfrac{15}{4}$ (b) $y = \dfrac{15}{4}$ (c) $y = \dfrac{45}{4}$

(d) The system is inconsistent, there is no solution (e) None of these

APPENDIX C

Interview Protocol

1. How do you feel about the subject of mathematics? Has that changed since you began this course?

2. How do you feel about your ability to do mathematics? Has that changed since you began this course?

3. Are there any resources that the instructor uses which particularly intrigued (engaged) you ?

4. Did you view any of the available online documents? Which ones? How often did you view them?

5. If you had to take this course again, can you think of anything that might assist in increasing your understanding of the subject material?

VITA

Amy Marie Marolt, a resident of Corinth, Mississippi, received her B.A. degree in mathematics from Mississippi State University in 2004. She then continued her studies at Mississippi State University where she received her M.S. in mathematics in 2006. In 2007, she entered the doctoral program in secondary education at the University of Mississippi. She began her teaching career at Northeast Mississippi Community College in 2005, where she is currently employed as a mathematics instructor.