THE RELATIONSHIP BETWEEN GRAPHING CALCULATOR USE AND THE DEVELOPMENT OF CLASSROOM NORMS IN AN EXEMPLARY TEACHER'S COLLEGE ALGEBRA COURSE

A Dissertation

by

SALLY SUE GERREN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2008

Major Subject: Curriculum & Instruction

THE RELATIONSHIP BETWEEN GRAPHING CALCULATOR USE AND THE DEVELOPMENT OF CLASSROOM NORMS IN AN EXEMPLARY TEACHER'S COLLEGE ALGEBRA COURSE

A Dissertation

by

SALLY SUE GERREN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Approved by:

Co-Chairs of Committee,	Gerald O. Kulm
	Carol L. Stuessy
Committee Members,	Barry L Boyd
	Cathleen C. Loving
Head of Department,	Dennie L. Smith

August 2008

Major Subject: Curriculum & Instruction

ABSTRACT

The Relationship between Graphing Calculator Use and the Development of Classroom Norms in an Exemplary Teacher's College Algebra Course. (August 2008)

Sally Sue Gerren, B. S., Texas A&M University; M. Ed., Texas A&M University

Co-Chairs of Advisory Committee: Dr. Gerald Kulm
Dr. Carol Stuessy

The purpose of this study was to advance knowledge about the relationship between graphing calculator use and classroom norm development. An interpretive case study design incorporating qualitative and quantitative research methods was used to explore the question: What happens when an exemplary teacher uses graphing calculators in a college algebra class? The purposively selected participants were the teacher and eleven students of a Texas community college algebra course. All 29 classes of the 14-week spring 2006 semester were observed in their entirety by the researcher. The theoretical frameworks guiding the study were the affective representation system and the Multiple Representations Model of Learning and Teaching with the use of the Mathematics and Science Classroom Observation System for data collection, analysis, and profiling of classroom lessons. Originally developed for grades K-12, the use of the instrument was extended to college algebra.

Triangulation of data sources using constant comparative and content analysis methods were used to support the three major findings: (1) The instructor's proactive orchestration of specialized instruction, support materials, and designed activities

contributed to the establishment of graphing calculator use as an essential part of classroom norms and promoted students' independent use of the tool; (2) The dynamic and interactive features of the TI-84 Plus graphing calculator facilitated the delivery of instruction at high cognitive levels during student interactive activities providing access to, exploration of, and use of multiple representations for some mathematical concepts and solutions not easily attainable using traditional methods; and (3) Although the majority of students had never used a graphing calculator before the course, all students used the tool at appropriate times during instructional activities, self-reporting that their use of the calculator was generally beneficial for enhancing their understanding of lessons and supporting class interactions. Additionally, all students independently chose to use the calculator during major assessments and reported knowledgeable use of the tool to facilitate improved test performance.

Replication of the study is limited because the norms developed in this case are unique to the teacher and students who negotiated their establishment. Suggestions are given regarding educational policies, reform practices, and research extensions.

DEDICATION

This dissertation is dedicated to David, my loving husband and best friend. His steadfast support of my education pursuits has made this work, the final requirement for my PhD degree, possible. My goal of achieving a PhD degree has become a reality because of his tireless devotion to helping me fulfill my dreams.

ACKNOWLEDGEMENTS

A dream is a daring adventure, a journey to carry you far, for when you can hold a dream in your heart, you surely can reach any star! *-anonymous*

I thank God for giving me the dream and the ability to accomplish the fulfillments for a PhD degree. Likewise, I am grateful to Dr. Robert Schuller whose prompting question, "What dreams would you attempt to fulfill if failure was not an option?" and words of hope rekindled the dream long stilled.

Fulfilling requirements for a PhD degree requires the assistance of knowledgeable individuals who can give valuable advice throughout the journey. I want to express my gratitude to my committee members who have supported me throughout the course of this research. I want to especially thank Dr. Charles Lamb for encouraging me to pursue a PhD degree and for serving as my committee chair until his retirement.

I want to thank Dr. Gerald Kulm for serving as the co-chair of my committee. I appreciate his sticking with me throughout all the twists, turns, and dead ends I have endured in trying to find my way to the desired destination of completion of the PhD requirements. His sage and valuable advice has helped provide guidance in my journey.

I extend my gratitude to Dr. Carol Stuessy for serving as the co-chair of my committee. I appreciate her permission to use her research, the Multiple Representations Model of Learning and Teaching and the Mathematics and Science Classroom Observation System, in my study. Her contributions and suggestions have been invaluable in helping me reach my desired goals.

I am very grateful to Dr. Cathleen Loving for the knowledge I have received through her instruction and for her advice in helping me produce a quality work of art. I am very thankful that she was a member of my committee.

I thank Dr. Barry Boyd for serving on my committee. He has always provided sound support for my educational endeavors. I appreciate his attention to detail in the editing process of this work.

I want to extend my gratitude to Mrs. A and students of the college algebra course who participated in the study. I appreciate the time they took to complete questionnaires and to answer my questions. Their contributions made this study possible.

I want to thank my friends for their support. I am very blessed to be surrounded by individuals who have encouraged me to reach my goals.

Lastly, but in no regard the least of these acknowledgements, I extend my deepest gratitude to my children who encouraged me to pursue a PhD degree. Rebecca, your support and help has been invaluable to me. I don’t know how I would have made it through my graduate studies without your assistance. Michael and Jonathan, I want to thank you for believing in my ability to accomplish such a lofty endeavor. I am truly blessed to have such a devoted family that has always supported my pursuits to fulfill my dreams. Dreams can become realities!

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

TABLE | Page

CHAPTER I

INTRODUCTION

The use of innovative educational practices and tools in learning environments that provide support for students' mathematical learning experiences is recommended by policymakers, researchers, and educational associations. Incorporating appropriate electronic technologies such as graphing calculators as instruments for teaching, learning, and doing mathematics is advocated by organizations such as the National Council of Teachers of Mathematics [NCTM], 2000), the Mathematical Association of America [MAA], 2004), and the American Mathematical Association of Two-Year Colleges [AMATYC], 2006).

Research supports the potential of the graphing calculator to provide opportunities for enhanced mathematical understanding by facilitating the exploration of concepts and by stimulating social interactions in the classroom environment (Doerr & Zangor, 2000; Goos, Galbraith, Renshaw, & Geiger, 2000; Hennessy, Fung, & Scanlon, 2001). The interactions between and among the teacher and students using various materials and graphing calculators in the context of the classroom is complex. The complex interactions in the classroom environment can be described through representational forms such as ways to communicate and the use of mathematical structures.

This dissertation follows the style of the *Journal for Research in Mathematics Education.*

The important role representations have in the teaching and learning of mathematics has been emphasized by the National Council of Teachers of Mathematics in the organization's view of representations:

> Representations should be treated as essential elements in supporting students' understanding of mathematical concepts and relationships; in communicating mathematical approaches, arguments, and understandings to one's self and to others; in recognizing connections among related mathematical concepts: and in applying mathematics to realistic problem situation through modeling (NCTM, 2000, p. 67).

The multiple features of representations offer the promotion of understanding, communication, connections, and applications of mathematic concepts.

Research has indicated that the potential of graphing calculator use to promote understanding between and among different representations depends on how the instrument is used by class members (Doerr & Zangor, 2000; Hennessy, et al., 2001). However, in what ways the use of the graphing calculator supports different representations so that effective strategies become routine for the classroom is not well understood.

A core finding from a synthesis of graphing calculator research by Burrill, Allison, Breaux, Kastberg, Leatham, & Sanchez (2002) states that student' gains in learning mathematics using graphing calculators depended on how the teacher used the tool. However, their synthesis indicated that more information is needed to help close the gaps in research on how teachers use graphing calculators. Regarding graphing calculator studies, Burrill et al. (2002) made the following suggestion, “Future research should seek to explore in greater depth the relationships between the use of handheld graphing technology and the classroom norms that give meaning and purpose to those uses” (p. 16). Additionally, the researchers pointed to the need for an observation protocol that would enable consistent interpretations and reports on how the graphing calculator is used in the classroom.

The present study drew from the research of Stuessy (2005) by using the theoretical Multiple Representations Model of Learning and Teaching with the use of the Mathematics and Science Classroom Observation Profile System (M-SCOPS). The M-SCOPS system, used for data collection, analysis, and profiling lessons, was extended from its original use in K-12 to college algebra.

Lessons were analyzed to provide information about the cognitive levels of receiving and acting on multiple representations used in the classroom and the classroom norms that were established during the course. In this study, classroom norms were defined as the patterns of expectations and regular practices that became routine behaviors through negotiations by class members in the context of teaching and learning college algebra concepts. Particular attention was given to how graphing calculator use influenced classroom norms and students’ understanding.

Problem Statement

More information is needed about the relationships between the significant aspects of the contexts in which the graphing calculator is used and the development of classroom norms in the teaching and learning of mathematics (Burrill et al., 2002).

Research Purpose

The purpose of this case study was fourfold (1) to investigate the relationships between and among aspects of a college algebra class and graphing calculators, (2) to determine significant influences of graphing calculator use on the development of classroom norms, (3) to evaluate how the calculator was used by class members, and (4) to contribute to research knowledge.

Research Questions

The main overarching question for the study was the following: What happens when an exemplary teacher uses graphing calculators in a college algebra class? Three inquiries support the main question:

1. What classroom behaviors and interactions become routine when graphing calculators are used and how does the tool promote those actions?
2. What instructional patterns and strategies occur when an exemplary teacher uses graphing calculators in a college algebra course?
3. How do students respond to the use of graphing calculators?

CHAPTER II

LITERATURE REVIEW

This literature review provides information about prior research relative to the present case study. Knowledge of prior research was necessary in order to build upon and to advance current understandings regarding effective instruction that promotes students' conceptual understandings and how quality learning environments can be designed and characterized. Central to this knowledge was the importance of viewing the components of the teaching and learning environment as an integrated whole as opposed to studying particular features in isolation.

The review of literature will include the theoretical frameworks for the study and prior research related to the complexities of teaching and learning mathematics. Prior research will include the Mathematic and Science Classroom Observation System, teacher, calculator, and norm studies. Included in the review will be information regarding the need to create learning environments that promote equitable access to mathematical ideas.

Two theories were used to facilitate an understanding of the occurrences that were of interest in the college algebra classroom. The Multiple Representations Model of Learning and Teaching (Stuessy, 2005) with the Mathematics and Science Classroom Observation System (M-SCOPS) provided guidance in the investigation of the research questions and the analysis of data. To provide an understanding of the attitudes described in the study, the perspective of the affective representation system presented by Goldin (2002, 2003) was used.

Included in the background research are studies about the observation system used, and a synthesis of information related to teacher, graphing calculator, and norm studies. The M-SCOPS was used to script, code, and profile classroom observations crucial for analysis of natural classroom phenomena and norm development. The studies regarding teacher and graphing calculators provided the background research that affected my design for the four questionnaires used in the study. The teacher research influenced the formation of the items included on the teacher lesson plan questionnaire and reflection form. Likewise, the formation of items on the students' initial background, lesson, and assessment questionnaires were influenced by the synthesis of graphing calculator research.

Theoretical Frameworks

Multiple Representations Model of Learning and Teaching

One of the theoretical perspectives guiding the study was the Multiple Representations Model of Learning and Teaching described by Stuessy (2005). The model provided a perspective on the processes of teaching and learning as receiving and acting on information in representational forms through interactions between individuals and personal interactions with instructional materials, tools, and activities. Teachers orchestrate instruction depending on their knowledge about content, pedagogy, and resources. Additionally, having experience with how students think aids the teachers in designing opportunities for student to build on their prior knowledge and to revise any misunderstanding they may have about the concept being studied through discourse and reflection.

Specific teaching and learning patterns in mathematics and science that support the use of representation, discourse, reflection, and revision for modeling real world situations are called *modeling practices*. These practices facilitate the construction, application, verification, and revision of internal models that are then expressed externally in communication with other individuals. The activities used in modeling practices include representations, experimentations, and applications. Participation in the activities requires the use of modeling actions such as transformations, explanations, visualizations, verification, and evaluations. Quality instructional modeling practices may contribute to advancing students' conceptual knowledge through representational fluency and the creation of new systems of understanding.

A representation is a "configuration" that can link to or stand for something else (Goldin, 2002, 2003). Representations that are related to each other are part of a structured system. A system may be internal or external. Internal systems are an individual's psychological and affective representations. Internal representations are the images or notions constructed and operated on and the processes used in individual thinking or feeling. External systems are representations that exist outside the individual. Systems may be embedded within other systems to create a hierarchy of systems. Of interest to this study were the systems of representations used in teaching and learning mathematics within a natural learning environment.

Representational forms of formal mathematics structures include combinations of symbols, concrete objects, or pictures. Symbols include the use of words, and numbers, and math notational systems. Pictures include the use of sketches, diagrams, and graphs. Concrete objects include three dimensional materials that can be handled or manipulated. Representational fluency is characterized by the ability to internally translate from one representational system form of an idea to other representations and understanding the relationships between them (Stuessy, 2005).

The representations serve as “devices” used to gain insight of the situation or concept using natural language and thoughts about mathematical structures (Cuoco, 2001). Likewise, Goldin (2003) states, “Mathematical concepts are learned powerfully when a variety of appropriate internal representations, with appropriate relationships among them have been developed . . . and (students) learn how to infer these systems from their observable, external manifestations” (p. 278). Emphasizing the critical need for providing opportunities for interplay between conceptual and expressed representations in the classroom, Goldin and Shteingold (2001) maintained that: “The interaction between internal and external representation is fundamental to effective teaching and learning” (p. 2).

Within the classroom, teachers make inferences about students’ internal knowledge based on their external productions. Students’ understanding can then be scaffolded to higher levels by the instructor’s use of the representational forms (Stuessy, 2005). The depth of understanding one has about a mathematical idea may be portrayed by the number and the strength of the connections between and among different mathematical representations (Coulombe & Berenson, 2001; Herman, 2007; Hiebert & Carpenter, 1992). Being able to access, use, and connect representations requires the use of certain types of media.

Different types of media are used to facilitate the interactions between internal and external representations. According to Goldin (2003), media include “static” or fixed representations like diagrams, “inert” media like textbooks, recording media like paper and pencil, and interactive media like graphing calculators. Dynamic technology such as the graphing calculator can facilitate the teaching and learning of various concepts through the different representations available through manipulation of the instrument (Goldin, 2002; Goldin & Shteingold, 2001; Hennessy et al., 2001; Kaput, 1989, 1992).

The Mathematics and Science Classroom Observation System

Used along with the Multiple Representations Model of Learning and Teaching, the Mathematics and Science Classroom Observation System (M-SCOPS) was used to facilitate data collection and analysis of the complex interaction that occur in the classroom between and among the instructor, students, activities, and educational instruments (Stuessy, 2005). The system was first used to promote a better understanding of the processes associated with teaching and learning and effective modeling practices in K-12 science and mathematic classrooms. The instrument provided a way to translate observation scripts into visual profiles highlighting the interactivity of teacher’s and students’ actions and use of multiple representations as reflective of the Multiple Representation Model of Learning and Teaching. Originally designed for use with preservice teachers, the M-SCOPS was extended to describe quality classroom learning environments in teaching and research contexts, to enhance teaching practices of novice and experienced teachers, and to correlate instructional patterns with academic performance (Stuessy, 2005). The tool facilitated documentation of the happenings in the classroom by dividing instruction into segments related to the students' focus throughout the learning events orchestrated by the teacher. When students' engagement changed to another focus another segment was created. For each of the segments information was recorded related to the action of the teacher, the actions of the students, and the information the students were receiving facilitating the documentation of varied instructional methods, discourse opportunities, and assessment strategies.

Each lesson segment was coded using established codes regarding the levels of instructional strategy and the complexity of cognitive information being received and acted on by the students. Forms of information received and acted upon were represented by symbols, objects, and pictures or simultaneous combination. Therefore, the level of instructional scaffolding and multiple representation use was documented throughout the lesson. The coded data is used to create a profile providing a visual view of the lesson.

The lesson profile was divided in the middle by a black line separating student activities into two parts: receiving, and acting on. Each segment time was converted into percentages forming the height of the segment with the colors red, yellow, green, and blue, corresponding respectively to instructional strategy, verbal information, pictorial information, and objects. Lesson profile analysis provided information on the pattern of activities, levels of instructional scaffolding, and use of multiple representations used to provide opportunities for student advancement in understanding and academic performance.

Affective Representation System

The second theoretical perspective used in the study was the affective representation system. The internal affective system impacts the teaching and learning processes. Research indicates that affective domain characteristics influence an individual's learning processes and subsequent achievement (Bloom, 1976; Goldin, 2002). According to Bloom, subject-related affect develops based the learners' perceptions of their achievement in the past, referred to as stable, long-term or "global" affect by Goldin. The learners' perceptions of their past history in turn influences how they perceive the present task in relation to their future goals according to Bloom and referred to as short-term changing states of feeling called "local" affect by Goldin. The "global" and "local" affect states are continually interacting with each other in complex ways. Goldin (2003) refers to temporary changing pathways as "local affect" that when established lead to the development of more stable constructs. Additionally, Bloom states that in order to alter negative affect characteristics toward a task learners need to gain satisfaction from the activity or some sense of accomplishment or achievement.

Background Research

Significant Studies

Although many research studies influenced my thinking about the present study, three studies especially impacted my decisions about the project's design to effectively address the research questions. The first study, Hennessy et al. (2001), focused on students' understanding of the connections between different representations of functions and how graphing calculator use can influence mathematical thinking and shape activities. Students from 5 regions of the United Kingdom enrolled in an entry level university mathematics course were observed during the study of graphs. There was a low response rate in the completion of questionnaire surveys when the course was finished with only 55 students completing the survey. A pair of students was observed while solving a math problem after the course was finished using talk-aloud verbal protocol analysis.

Two main findings of the Hennessy et al. (2001) study included (1) the use of the graphing calculator was firmly embedded within and inseparable from the mathematical activity being undertaken, and (2) the graphing calculator served an integral role in influencing mathematical thinking and in shaping activity. Their findings led to the recommendation that additional research was needed on how the graphing calculator was used to support mathematics activity and to help scaffold learning beyond what the student can already do without over-relying on the calculator and accepting answers without understanding.

The second study, Goos et al. (2003), was a 3 year longitudinal study of senior secondary school classrooms that investigated the role of graphing calculators in supporting students' exploration of mathematical ideas and in mediating their class interactions. Data collection included the observations, interviews, questionnaire surveys, and recording instruments. Five classes were observed one time a week. Two main findings of the study included (1) teachers pedagogical beliefs and values played an important part in shaping technology mediated learning opportunities, and (2) the use of graphing calculators re-shaped interactions between teachers, students, and the tool itself. Their findings led to the recommendation for further study of the mathematical and pedagogical challenges faced by teachers in technology enhanced classrooms to accomplish goals of establishing collaborative learning environments.

The third study used a questionnaire survey that influenced the design of the present study's questionnaires. Smith and Shotsberger (1997) studied 4 college algebra classes taught by two professors. Each professor taught a class with calculators and a class without calculators. Students completed pre-measure and post-measure of student attitudes collected using Likert-scale items and opinion questionnaires. Comparison of students' responses were made between the 4 college algebra classes that two professors taught with each professor teaching one class with a graphing calculator and the other class without the calculator.

Two findings from the research relative to the present study related to students in the classes where graphing calculators were used (1) the majority of the students believed the graphing calculator promoted better understanding of function characteristics, and (2) most students indicated a preference to using the graphing calculator rather than not using it. The findings led to a recommendation for further study on patterns of calculator use by class members and how calculator use could positively impact student learning for different algebra topics.

Certain features of the three studies previously described to design an interpretive case study to get a more holistic view of graphing calculator in the classroom. The studies influenced my design in several ways (1) observe every class in its entirety instead of certain classes or units, (2) modify items from their questionnaires and surveys to create my own instruments, and (3) create questionnaires to obtain students' reflections and comments about graphing calculator use immediately following each class. Observation of classes during the entire course offered opportunities to gain an understanding of teacher' and students' perspectives regarding graphing calculator use as well as how and when the tool was used by the class members.

Teacher Research

The essential role the teacher plays in orchestrating the components of the classroom environment is highlighted in the following teacher studies. Research indicates that educators make instructional decisions depending on what they know and believe about mathematics (Thompson, 1992; Wilson, 1990), pedagogy related to mathematics (Abrams, 2001; Friedlander & Tabach 2001; Goos, 2004; Shulman, 1986), and student learning (Pesek & Kirshner, 2002). Teachers' beliefs on how learning occurs directly influences how instruction is delivered, the tools selected to facilitate the process (Cooney & Shealy, 1997), and expectations for student participation and engagement (Henningsen & Stein, 2002; Howard & Baird, 2000).

An important part of an instructor's practice is reflection and analysis of the teaching and learning experiences of the classroom. NCTM (1991) asserts that:

> The teacher of mathematics should engage in ongoing analysis of teaching and learning by . . . examining effects of the tasks, discourse, and learning environment on students' mathematical knowledge, skills, and dispositions, in order to ensure that every student is learning sound and significant mathematics and is developing a positive disposition toward mathematics . . . (p. 63).

Therefore, effective instructors analyze and reflect upon classroom happenings and revise their plans based on how students' respond to the instructional activities and the materials and tools used.

One of the tools mathematic instructors can chose to use is the graphing calculator. NCTM (2000) advocates the use of graphing calculators for teaching and learning mathematics but maintains that the teacher must make decisions about the appropriate use of the tool during instruction. The assertion is supported by the research of Heid (2003) that emphasized, "The effectiveness of any tool depends entirely on the decisions made regarding use" (p. 50).

The preceding research indicated that teachers make instructional decisions based on their beliefs, knowledge, and experiences. The choice of activities, materials, and tools used for instructional delivery are unique per instructor. The studies influenced my perspectives in attempting to gain insight to the reasons behind the instructional decisions made by the teacher in this study.

Graphing Calculator Research

Graphing calculator research reported favorable outcomes, usage concerns, and instructional suggestions regarding the tool's use that influenced the study. Results of research findings, concerns, and suggestions were used to formulate the teacher and students' questionnaires and influenced my thinking about the study. Studies supporting positive results included the following: promotion of students' achievement in mathematics (Heller, Curtis, Jaffe, & Verboncoeur, 2005), improvement attitudes towards mathematics (Hennessy et al., 2001), and reduction of gaps between genders (Cassity, 1997).

Research indicated that students' use of the graphing calculator depended on their knowledge of the instrument's capabilities and the students' mathematics knowledge (Goos et al., 2003). Concerns about students relying too much on the calculator instead of developing an understanding of the underlying patterns and principles of the topic being studied was reported by Hennessy et al. (2001).

Suggestions for instructional practice included careful attention to instructional design and activities related to graphing calculator use and for teachers to take the time to help students understand the tool's limitations and constraints, to use the tool appropriately, and to analyze the reasonableness of calculator results (Guin & Trouche, 1999). Such instruction provides opportunities for students to develop appropriate "intelligent partnerships" with the calculator promoting improved mathematical competence and enhanced mathematical understanding (Jones, 1995). Therefore, the teacher's knowledge about the calculator's capabilities and limitations will influence the utilization of the tool (Doerr & Zangor, 2000) along with promoting communication in the classroom (Mariotti, 2002).

In the classroom, the graphing calculator can be used as an educational tool to facilitate different ways of thinking about and doing mathematics and to promote class interactions. Burrill (1992) maintains that the use of the graphing calculator as an instructional instrument provides opportunities for exploring and discovering concepts in new ways as opposed to paper and pencil methods. Studies support the potential of graphing calculator use to promote class interactions and collaboration. Referring to the graphing calculator as a "personal mathematical tool" Goos et al. (2003) reported that the tool facilitated the "sharing of knowledge" in the classroom. Likewise Hennessy et al. (2001) reported that the graphing calculator served as"mediator" in students' collaboration by providing an external reference object and as a "cognitive prop" in facilitating translations between multiple representations.

On the other hand, a study by Herman (2007) indicated that some students preferred algebraic methods using paper and pencil over graphing calculator approaches. Students in the freshman-level advanced algebra college class were knowledgeable about graphing calculator capabilities and felt they had a deeper understanding of functional concepts when they were able to make connections among the different representations. However, the study's findings indicated that students continued to use symbolic approaches as their main strategy for solving problems even though a calculator approach would have been easier and faster. Reasons why one representation or solution strategy was favored over the others were given as the students' perception in regard to the following: what was considered mathematically proper, the instructors modeling of representations, and the efficiency of the representation to produce an answer. The researcher suggested that the students may have been more favorable to graphing calculator approaches if students would have had more time to master their use of the tool and recommended further study on instructional methods used to help students find the value in efficient use of the tool.

Norm Research

Classroom dynamics involves the complex interactions between and among class members and the educational materials, activities, and tools used for teaching and learning. Inferred and observed behaviors or implicit and explicit rules that become established or routine for a class are negotiated agreements between members of the learning community and are often called classroom norms. The negotiation is ongoing as class members interact through participating in teaching and learning activities. Instructors play a central role in initiating and guiding the development of norms through their selection of instructional strategies, tasks (Fassinger, 2000; Yackel & Cobb, 1996) and practices (Goos, 2004; Kazemi & Stipek, 2002). Norms that are specific to the mathematical aspects of classroom activities are called sociomathematical norms as coined by Yackel and Cobb (1996). Students develop their mathematical understandings as they participate in negotiating both classroom and sociomathematical norms based on the beliefs or expectations they bring to the classroom.

Certain norms and traits related to class size and emotional climate associated with high levels of student participation were found in a survey questionnaire study of 51 classes in a Midwestern liberal arts college (Fassinger, 2000). Class environments where high levels of student participation took place were reported by students to be cooperative, supportive, respectful, and offered opportunities for members' interactions. Perceiving that instructors with high class participation were probably more skilled at interpreting students' perceptions, the researcher suggested that educators strive to develop strategies to increase students' confidence and comfort levels in the classroom. One finding of the study related to class size indicated that the classes with a mean of fifteen students had more social interactions when compared with classes that had a mean of twenty-seven students.

Equity Promotion

The preceding research supports the critical nature of representations in communicating mathematical ideas given opportunities to learn in the dynamic setting of the classroom. Moreover, creating classroom environments that promote equity and students' achievement levels in mathematics is a goal of international and national researchers and educators promoted through NCTM (2000) and the federal government. The legislation of the *No Child Left Behind Act* mandates the incorporation of educational strategies that serve to narrow the achievement gap between varied student populations thus fostering opportunities for success for all students in their academic performances and future aspirations. Concerns about supporting students' mathematics achievements in two year colleges and lower division mathematics education at four-year colleges and universities have prompted the AMATYC (2006) to issue new standards calling for college mathematics faculty to implement quality instructional practices based on current research and to align college standards with those of NCTM (2000) for school mathematics. The standards include the use of teaching strategies to enhance student learning through active participation in learning and the use of technology, such as graphing calculators, to provide opportunities of access and academic success for all students.

Summary

The review of literature presented described the theoretical frameworks and past research that influenced this study. Additionally, goals to implement practices that enhance students' learning and achievement have been discussed. The potential of the graphing calculator to enhance teaching and learning processes through instructional strategies orchestrated by a skillful educator has been emphasized. This study aims to address the recommendations of past research by investigating how an exemplary teacher orchestrated graphing calculator use with specialized activities and materials to promote desired classroom norms and to enhance students' learning and performance.

CHAPTER III

METHODOLOGY

An interpretative case study design as described by Merriam (1998) was used to investigate the complex phenomenon of the integrated use of graphing calculators by an exemplary teacher in a college algebra course. Characteristics of the design features the collection of data with the intent of identifying, analyzing, and interpreting recurring patterns for the purposes of understanding any relationships that may exist between or among the focuses of interest that includes the participants' perspectives. The study's focuses were on the development of classroom norms, how the calculator was used in the classroom, and students' responses to graphing calculator use. Topics in this chapter describe the study's methodology related to the procedure, population, setting, data collection, instruments, analysis, validity, reliability, ethics, and assumptions.

Procedure

The purpose of this study was to identify and interpret activities and behaviors within the complex environment of the natural classroom setting. Since a holistic design was required to study the phenomenon, case study techniques were used to provide an in depth understanding of the happenings within the classroom. Both qualitative and quantitative data were used in developing the case study. The three main relationships explored during the project were (1) the influence of graphing calculator use on the development of classroom norms, (2) how the graphing calculator was used by class members during class sessions, and (3) how students responded to graphing calculator use.

Population

The population for this case study was purposively selected. The population included the instructor and the students enrolled in one northeast Texas community college algebra class during the spring 2006 semester. Twelve students originally enrolled in the class agreed to participate in the study but one student started attending another section of the course. Data collected related to this student was deleted from the data used for analysis.

Students

Students completed an initial background questionnaire the first day of class. A summary of the information from the questionnaire is presented in Table 1.

Table 1
Summary of Students' Background Information

Student Code	Gender	Age Category	Race	Math	Calculator Experience
1	Female	Nontraditional	Caucasian	Remedial	None
2	Female	Nontraditional	Caucasian	College	None
3	Female	Nontraditional	Caucasian	Remedial	None
4	Female	Nontraditional	Caucasian	Remedial	None
5	Female	Nontraditional	Caucasian	High School	None
6	Female	Nontraditional	Caucasian	Remedial	Neutral
7	Female	Precollege	Caucasian	High School	Favorable
8	Female	Precollege	Caucasian	High School	Favorable
9	Female	Traditional	Caucasian	High School	Favorable
10	Male	Traditional	Caucasian	High School	Unfavorable
11	Male	Nontraditional	Caucasian	Remedial	None

Of the eleven students who participated in the study, nine were females and two were males. Two students were precollege age still enrolled in high school classes, two were traditional college age between 18 and 24 years old, and seven were nontraditional college age being over 24 years old. All students were of Caucasian race. The following math classes were completed by the six nontraditional students; one high school math class, five remedial college math courses, and one college level math course.

Graphing calculator experience varied among the eleven students. Six students had no prior experience with graphing calculators. Five students completed a Likert-type questionnaire related to their experiences with graphing calculators. Mrs. A also completed the same Likert-type questionnaire as the student participants.

The students' Likert scores were compared to Mrs. A's raw score of 35 to indicate a positive response toward knowledge and use of graphing calculators. A score of 21 indicated an undecided or neutral response. Scores that were greater than 21 implied a positive response toward knowledge and use of graphing calculators. Scores that were less than 21 suggested an unfavorable response toward knowledge or use of the tool. Based on these measures toward their knowledge and use of graphing calculators, three of the students indicated favorable responses, one student related a neutral response, and one student scored an unfavorable response.

Instructor

Interest in this particular instructor stemmed from an unpublished study on issues related to teacher change that was conducted by the researcher as a graduate course assignment. This teacher reported that the integration of the graphing calculator into her teaching resulted in her ability to teach mathematical concepts with greater depth and meaning. I wanted to learn about the practices that were used to accomplish such higher-level delivery of instruction. In the study, this teacher will be referred to as Mrs. A.

Mrs. A's formal education included a Bachelor of Science in Secondary Education with an emphasis in the teaching of computer science and mathematics in 1987 and a Master of Science Degree in Secondary and Higher Education with an emphasis in teaching college mathematics in 2002. She continued to advance her knowledge of mathematics and pedagogical strategies by participating in various professional development activities. During her teaching career, Mrs. A has attended two mathematics conferences each year, one Eisenhower Grant institute, one environmental institute, and numerous curriculum and technology workshops.

Mrs. A's teaching experiences included both secondary and college mathematics. She taught fifteen years at a public high school with a diverse student population. She also taught the following secondary courses as regular and honors classes: algebra I, algebra II, geometry, trigonometry, pre-calculus, calculus, and statistics, as well as preparation classes for the state assessment tests and summer school. She also coached university interscholastic leagues teams in mathematics, calculator, and number sense.

During this time she taught developmental mathematics classes for the community college. After receiving her masters' degree in 2002, she began teaching at the community college full time as well as teaching dual credit courses at four area high schools. College courses she has taught include the following: college algebra, statistics, trigonometry, pre-calculus, calculus, fundamentals of math I & II (mathematics for elementary teachers), and math for business & social sciences I & II.

During the academic year 2004-2005, Mrs. A received the *Extra Mile Award* at the campus where she teaches. She wrote about this award on her faculty service report for the academic year 2005-2006:

> I feel that I am effective teacher. I received the Extra Mile Award-an award from the students for going the "extra mile." This award is very dear to me, since it reflects the student's opinion of my effectiveness. I strive to not only impart knowledge, but also a love and appreciation for the knowledge, while at the same time, interacting with my fellow humans with the love, care and compassion that the Lord has shown for each of us humans. While I fall very short of this goal, nevertheless, I strive for it each day. (R-E-1)

This comment reflects her love for teaching and concern she has for other people. She also made the following comment in the report: "I am a team member. I lend a helping hand to any student, staff or faculty when a need is noticed" (R-E-1). Helping other people can be observed by other individuals.

Mrs. A's concern for her students was also noticed by her administrator. The college dean wrote the following comments on her faculty appraisal for the academic 2005-2006: "(Mrs. A) goes above and beyond the normal expectations of faculty members with regards to helping students. She holds extra study sessions and even comes in on the weekend to help her students. She has a great sense of obligation to get her students through the course material." At another section of the appraisal he writes:

"(Mrs. A) establishes a good rapport with her students and helps them overcome anxieties they may have about math" (R-E-1). Mrs. A's dedications to helping students learn the required mathematics for their course has been acknowledged by her students and the college dean.

Research Setting

The research setting was a classroom within a small community college. The classroom was arranged with an aisle in the middle of the room with four rows of rectangular tables on each side to sit four students to a table facing the front. A rectangular table for the instructor's use was in the front of the classroom with an overhead projector on it. A large rectangular white marking board was located on the front wall. Two posters were hung in the room. One was a TI 84-Plus graphing calculator poster displayed on the front wall beside the white board. The other poster illustrated conic section concepts and was hung on the back wall.

Classes were scheduled for Monday and Wednesday afternoons from 4:30 pm to 6:00 pm. Mrs. A taught another college algebra class that met only one day a week, Monday evenings from 6:00-9:00 p.m. Students from the evening class sometimes attended the afternoon classes if they missed the evening class or needed more help. No personal data was received from these students except their interactions with members of the class. Mrs. A stated that it has been her experience that students who struggle in math seem to do better in the afternoon classes that meet two times a week as compared to the class that meets one night a week (I-T-4). The students in the night classes seemed to just want to get the class over with and the enrollment in those classes was generally higher than in the afternoon classes.

The college algebra objectives, course textbook (Sullivan, 2004) and the textbook publisher's supplemental CD test bank were the same for all teachers of college algebra for this community college system. The course textbook used was Sullivan (2004), *College Algebra*, published by Prentice-Hall. The college required instructors to administer a minimum of two tests and to maintain student attendance records but left the method of instruction up to the individual teachers.

Instrumentation

Data collection instruments included the following: the classroom observation system, teacher and student questionnaires, field notes, informal interviews, and a variety of documents. Table 2 presents an overview of the data collection instruments used in the study with the frequency of their use and their purpose.

Classroom Observation System

The classroom observation system used in the study was the M-SCOPS developed by Stuessy (2005) and selected because of the detail offered by the scripting sheet, coding schemes, and visual profile sheet (see Appendix A). The scripting sheet was used to record data in time segments according to changes in students' focus of attention during the lesson. Data to be recorded included the time segments, a summary of what the teacher was doing, the level of cognitive representations the students were receiving, and what the students were doing and the level of cognitive representations they were action on. The complexity of instructional delivery was recorded according to the teacher's level of scaffolding for the students. Students' performance and initiative was recorded according to the level of their response to the teacher's instructions or directions. Action levels of multiple representations as received by the teacher and performed by the students were recorded. The system's coding scheme was used for

Table 2
Data Collection Instruments, Number of Sessions, Purpose, and Audit Trail Codes

Instrument Code	Number of Sessions	Purpose	Audit Trail Code
M-SCOPS Observation System: scripting sheet, coding schemes, & visual profile form	23	To collect, code, and profile happenings in the classroom, completed after ach lesson	M-SCOPS (M); Visual Profile (V)
Teacher Lesson Plan Questionnaire	19	To collect data about objectives, GC use, and comments, collected from instructor	Questionnaire (Q); Teacher (T)
Initial Student Questionnaire	1	To collect demographic data and information about students' math background, collected in the first class	Questionnaire (Q); Initial (I)
Student Lesson Questionnaire	23	To collect data regarding students' responses to GC use, collected after each lesson	Questionnaire (Q); Lesson (L)
Student Assessment Questionnaire	5	To collect data regarding GC use during tests, collected after each major assessment	Questionnaire (Q); Assessment (A)
Informal Interview	As needed	To clarify information or ask questions	Interview (I)
Field Notes	29	To collect information about class happenings and the environment, taken each class	Field Notes (F)
Varied Documents (hand-outs, tests, student work, and records)	As needed	To collect data pertinent to the study	Documents (D); Hand-outs (H); Tests (B); Student work (W); Records (R)

coding the data on the scripting sheet. A visual profile of the data was created using color codes and numbers to represent the different levels of activity of both the teacher and the students throughout the lesson. The visual profile for each lesson provided an overview of when and how the graphing calculator was used by the teacher and the students throughout the class.

My original intent doing class observations was to record data by hand directly on the M-SCOPS scripting sheet form (see Appendix A). However, this was time consuming and I felt that I was missing the opportunity to collect additional field note data relevant to the study. Therefore, during the third class I decided to type the data pertinent to the scripting form using my laptop's word processing program. The advantage of this technique permitted me to describe information pertinent to the study faster enabling me to provide a chronological description of the occurrences of the class environment in more detail.

Teacher and Student Questionnaires

The teacher and student questionnaires were constructed by the researcher (see Appendix B). Items on the questionnaires were modified from instruments used in research described previously (Goos et al., 2003; Hennessy et al., 2001; Smith & Shotsberger, 1997). The questionnaires were examined for face and content validity by a panel of experts consisting of four professors with PhD's and two college algebra instructors. The professors reviewing the questionnaires were knowledgeable about educational research practices and had experience with analyzing questionnaire construction. The college algebra instructors were experienced educators who integrated graphing calculator into their teaching and were familiar with calculator issues and research.

The majority of items on the students' lesson and assessment questionnaires were influenced by the research of Hennessy et al. (2001) conducted at a university in the United Kingdom. Their study included a four part questionnaire survey administered to students through the mail after completing an entry level university mathematics course that included integrated graphing calculator use. The questionnaire consisted of open and closed items about the calculator, the course activities, their perceptions about the calculator, and the potential of the calculator as a learning aid.

Questions were asked about the concepts that the calculator helped with understanding, the value of the calculator as an overall tool for learning mathematics, the ease of doing mathematics with the calculator, and if they ever used the calculator without really understanding what they were doing. Fifty-five students completed and returned the questionnaire survey, a response rate of 24%.

In this present study, my intent was to create a lesson and assessment questionnaire that would elicit students' reflections about aspects of graphing calculator use immediately following either the lessons or assessments. I wanted the questionnaire to be short enough so that all students in attendance would take the time to give accurate reflections. The questionnaires consisted of both Likert-type statement items designed to be completed quickly and free response items if students wanted to take the time to elaborate on their calculator experience.

Teacher Lesson Plan Questionnaires

The teacher lesson plan questionnaires were completed by the participating teacher for class sessions during the semester. The questionnaire served to gather information about the intended instructional objective(s), classroom organization, use of materials, reasons for choosing to use the graphing calculator, the intended use of the graphing calculator by the students, and the expected learning outcome(s) for students. The teacher wrote reflections about the class session on the back of the questionnaire or verbal reflections during informal interviews after the class. Data from the teacher's lesson questionnaires were triangulated with the observation data and other relevant data to support any finding related to the study. The informal interview format was used to address questions that arose related to the class.

Student Questionnaires

The three student questionnaires were completed by the participating students. The first questionnaire (see Appendix B) was completed on the first day of class by the student participants and was designed to collect general information about the students, their experiences with graphing calculators, and their previous mathematics courses. If students had used graphing calculators before their enrollment in this class, they completed seven 5-point positively worded Likert-type questions designed to assign each student a score related to their responses.

The items on the questionnaires were modified from the research of Goos et al. (2000) and represent aspects regarding students' use of graphing calculators according to their study. The highest possible score of "35" indicated that the individual was knowledgeable about the graphing calculator and had experience in using the instrument. Students' scores were used to categorize them according to their responses as knowledgeable or experienced, neutral or undecided, and lacking knowledge or experience.

The information requested regarding previous courses and graphing calculator access was related to research by Smith and Shotsberger (1997) who speculated that the percentage of time college algebra students spent using the calculator was related to their previous experiences and courses. The data related to gender and ethnic background was used for checking for any significant differences on students' calculator experience in efforts to identify equity issues related to graphing calculator use.

The student lesson and assessment questionnaires (see Appendix B) were designed for students to record their reflections about graphing calculator use at the end of each lesson or assessment. The Likert-type items on the lesson and assessment surveys were related to concerns regarding graphing calculator use from other studies (Goos, et al., 2003; Hennessy, et al., 2001). This information was used to compare with data from other sources such as the field notes and the teacher's lesson plan questionnaires to support relevant information regarding any findings. An informal interview format was used to clarify responses on students' surveys or to ask questions related to observed situations in class.

Field Notes

Field notes were taken during each of the 29 classes. Field notes for the first two classes were hand written and later typed. Starting with the third class, I typed the field notes using the word processing program on my laptop. Field notes were taken before class actually started when students entered the room and continued until the end of the class.

Informal Teacher and Student Interviews

I planned that informal interviews be conducted as needed throughout the study. Some of the students talked to me and offered information when they turned in their completed student questionnaires. I considered these talks as informal interviews. I had a few talks with the instructor when I needed additional information. I considered these talks as informal interviews as well.

Documents

Various documents were received during the project. From the instructor, I received copies of class handouts, quizzes, tests, grades, e-mail homework, students' course evaluation forms, and a teacher evaluation form. One student gave me a copy of her college transcripts and a copy of the record containing her diagnosis of a mathematics disability.

Data Collection

As the principal investigator, I gathered data using various qualitative and quantitative research techniques. I received training in the data collection techniques used and was knowledgeable about the mathematical concepts and graphing calculator techniques for this level of mathematics. Data was collected during every class of the 14-week, semester-long course. I usually arrived about 15 minutes before the class started. I set up my laptop up on a student desk located at the back of the class. I collected data during the entire class period for each of the 29 classes. As a non-participant observer, I hoped my presence during all the classes would reduce any negative observer effects on the students.

I was introduced to the students toward the end of the first class. I explained the purpose of my research study to the students and went over the consent forms (see Appendix C) with them. I told them that I was interested in knowing how they felt about using the graphing calculator during instructional lessons and major assessments. I emphasized that they were the experts on how they felt about using the graphing calculator. All twelve students agreed to participate in the study.

Students filled out the initial background questionnaire during the first class. Students filled out a lesson questionnaire after the graphing calculator orientation activity. Mrs. A was given teacher lesson plan questionnaires forms for the entire semester (see Appendix B). She gave me the completed questionnaires when she was finished filling them out each week. I received copies of the class handouts, quizzes, tests, e-mail homework assignment, and students' course evaluation forms.

Before Mrs. A dismissed the classes, she said, "I think Mrs. Gerren has something for you to fill out. You can leave when you are finished with it." I often reminded the students that they were the experts on how they felt about using the calculator as I passed out the questionnaires. During assessment classes, students picked up the assessment questionnaire when they turned in their test to the instructor. Students either finished the questionnaire and brought it back to me or left it on their tables. Students put their names on both the lesson and assessment questionnaires.

Data Analysis

An interpretational analysis was used to examine the data collected for the study. The process was completed in several steps. Data analysis for the M-SCOPS occurred after each class as described by Stuessy (2005). The constant comparative method, developed by Glaser and Strauss (as cited in Merriam, 1998) was used to analyze the observational data for patterns of recurring behavior to identify possible developing classroom norms throughout the semester. Content analysis of teacher and student questionnaires and documents occurred after the data collection process was completed.

Data from the M-SCOPS scripting notes were analyzed and coded according to the system's coding schemes after each of the 23 lesson sessions. Visual profiles of the data were than created. The constant comparative method was used to analyze the levels of representational scaffolding strategies during lessons, between lesson sequences, and the four instructional units to determine patterns in the levels of reception and direction provided by the instructor and the subsequent levels of performance and initiative of the students. Likewise, the complexity of representational scaffolding used in receiving and performing of multiple representations were analyzed to determine patterns during lessons, between lesson sequences, and the instructional units. Analyzed data was then used to determine any relationships between and among the data.

Analysis of the field notes from the classroom observations was used to identify norms that developed during the semester after the data collection was completed. The constant comparative method was used to analyze the data to identify any emergent patterns. A coding scheme for the identified patterns was then developed. Recurring behavior patterns were identified and grouped into categories. Formulation of the final categories and identified behavior were a result of a four part refinement process. The teacher's lesson plan questionnaires and students' lesson questionnaires were analyzed to identify any data that could be used for triangulating data and sources to support the classroom norms identified.

Validity, Reliability, and Ethics

To enhance the trustworthiness of the project, the strategies recommended by Merriam (1998) dealing with issues of validity, reliability and ethics were used. The internal validity of the project was strengthened by using the following strategies: long-term observation at the site, triangulation of multiple sources of data, checking with members to verify interpretations of observations and/or interviews, examination of findings by colleagues, and stating the researcher's assumptions.

Strategies to strengthen the reliability of the results in terms of consistency and dependability include providing the assumptions and framework underlying the study, using multiple methods of data collection and analysis, using an audit trail to describe how and when data were collected, describing how the study was conducted, and describing how the findings were derived from the data. To enhance the external validity of the study, rich descriptions of class occurrences were provided so readers would be able to determine whether or not the findings could be transferred to their situation. Additionally, the findings were interpreted in terms of prior research to strengthen the study's external validity.

The study was conducted with high ethical considerations. The purposes of the study were explained to the participants both verbally and written on the first day of class. Since one of the purposes of the study was to understand the participants' perspectives, I emphasized that they were the experts on how they felt about using the calculator. I wanted them to act naturally in the classroom during the observations and to respond honestly to the questionnaires and to interview questions. Students that agreed to participate in the study were free to ask questions during the study and they could withdraw from the project at any time. Subjects' identities were kept confidential.

Instructor's Influence

The instructor had an influence on the design from the earliest planning stages. Although agreeable to let me do the study on one of her college algebra classes, she was concerned how about the data collection process would influence her students. In an interview, she said that it had been her experience that the students who took college algebra were nervous about the class and she didn't want my data collection techniques to aggravate their anxiety.

Therefore, she did not want a pre-mathematics and post-test because she felt this would "freak them out" so I did not proceed with that idea. She also felt the use of video-taping and audio-taping would make students apprehensive about participating in class activities and interactions so I did not use those recording instruments. She was concerned about the amount of time it would take students to complete the questionnaires that I wanted to have students complete after each class, so I put together the questionnaires keeping in mind the amount of time it would take students to complete it. I told her for this study the students were the experts on their perspectives about graphing calculator use.

Researcher's Qualifications and Assumptions

I conducted this study as partial fulfillment for the requirement of Doctor of Philosophy at Texas A&M University at College Station, Texas. My major study was in the field of curriculum and instruction with a minor in mathematics education. I believe the knowledge I have received in pursuit of this degree has qualified me as a competent researcher for this project. As a public classroom teacher for thirteen years, I have taught mathematics subjects from 7^{th} grade through to precalculus. I am knowledgeable about the content and graphing calculator use for college algebra.

I believed that the graphing calculator could be used to enhance or to complicate the teaching and learning of mathematics, depending on how the tool was used or perceived by the user. I believed that individuals have different perspectives on calculator use that impacts their use of the tool. I wanted to gain insight on their views and any changes to their perspectives during the course. Therefore, the following two assumptions were made (1) the participants exhibited normal behavior and interactions during classroom observations, and (2) the participants responded truthfully when filling out the questionnaires and during interviews.

Summary

This chapter has provided information about the research methodology used for the present study. An interpretive case study design and a purposively selected population were used to facilitate the investigations required to address the research questions. Information was given about the qualitative and quantitative methods used regarding instrumentation, data collection, and data analysis. Lastly, issues regarding the validity, reliability, and ethics for the study were addressed.

CHAPTER IV

RESULTS

This interpretive case study was designed to examine the happening in a semester-long, fourteen-week college algebra course. Qualitative and quantitative measures previously described were used to collect data relevant to the project using the conceptual frameworks of the Multiple Representations Model of Learning and Teaching (Stuessy, 2005) and the affective representation system (Goldin, 2003) as the lens from which the data was viewed. The constant comparison method and content analysis was used to identify patterns of behavior data. Triangulation of data from M-SCOPS, questionnaires, interviews, field notes, and documents were used to support the results of the study that addressed the research questions. The following three questions were addressed:

1. What classroom behaviors and interactions become routine when graphing calculators are used?
2. How does the graphing calculator promote those behaviors?
3. How do students respond to the use of the graphing calculators?

The four main sections contained in this chapter present the results of the investigations designed to provide answers to the research questions and closes with a chapter summary. The three main results of the present study will be described in more detail in the appropriate sections:

1. The instructor's proactive orchestration of specialized instruction, support materials, and designed activities contributed to the establishment of graphing calculator use as an essential part of classroom norms and promoted students' independent use of the tool.
2. The dynamic and interactive features of the graphing calculator facilitated the delivery of instruction at high cognitive levels during student interactive activities by providing access to, exploration of, and use of multiple representations for some mathematical concepts and solutions not easily attainable using traditional approaches using paper and pencil methods.
3. Students self-reported that graphing calculator use was generally beneficial for enhancing their understanding of lessons, facilitating class interactions during lessons, and improving performance on tests.

The first part of the chapter describes how the instructor's goals were expressed as expectations for students' behavior that led to the development of classroom norms. The second part of the chapter describes how the graphing calculator was used to facilitate instruction at high cognitive levels during participatory activities. The third section provides findings related to how the students responded to the use of the graphing calculators during the course. The last section provides a summary of the chapter.

Section I: Class Happenings and Norm Development

Observation data from all 29 classes, interviews, and varied document data were analyzed using constant comparative and content analysis methods that led to the formulation of the first finding: the instructor's proactive orchestration of specialized instruction, support materials, and designed activities contributed to the establishment of graphing calculator use as an essential part of classroom norms.

The following analyses provided support for the finding: all members had a personal graphing calculator that was visible and ready to be used during all 29 classes, supplemental instructional materials were provided to support students' use of the tool during class activities and independent use starting with the first day of class, direct instruction and guided practice was given on how and when to use the tool, students' use of the tool was informally assessed by the teacher and other students, and the instructor's use of a graphing calculator screen image projection provided a shared visual image that facilitated instruction and promoted class interactions. Mrs. A's expressed goals and expectations for the class were reflected in her teaching practices.

Instructor's Goals

Mrs. A's goals for the class are given and descriptions about her proactive use of materials and activities for instruction and use of the graphing calculator provide information about her practices and classroom norm development. Instructional activities were planned to accomplish explicitly stated goals and objectives. The intertwined goals and objectives were grouped according to related aspects of affect, cognition, classroom, and mathematical representational systems. Decisions regarding graphing calculator use depended upon Mrs. A's instructional objectives for the learning activity and the promotion of one or more overall goals. An overview of the goals and objectives for the course is presented in Table 3.

Interplay between and among the representational systems was intricately and reflexively related. Goals related to these systems included the promotion of positive emotional and learning experiences where members' participation and interactions were supported within a safe environment cultivating a community of learners. Descriptions of activities and strategies Mrs. A used related to the affective and class environment representational systems will show how aspects of the systems were addressed in her practice. The cognitive and mathematical aspects are included in the class environment representational system's descriptions.

Table 3

Instructor's Stated Goals and Objectives

Audit Code	Goals and Objectives
	Affective Aspects:
Q-T-3	To create students' feelings of being academically safe to take risks in learning
Q-T-1	To increase students comfort levels using the graphing calculator
	Cognitive Aspects:
O-L-1; D-C-1	To advance students' understanding of mathematical concepts and skills related to the college algebra objectives
	Class Environmental Aspects:
O-L-2;Q-T-3	To promote interactions among members
O-L-3	To promote the creation of a community of learners
	Mathematical Aspects:
O-L-1; D-C-1	To teach the required college algebra objectives
O-L-2; O-L-10	To promote students' use of the graphing calculator

Aspects of Representation Systems

Affective Representation System

Aspects of the affective representation system described include feelings about mathematics and calculators, feeling safe, overcoming anxiety, and keeping stress reduced for the students.

Feelings about Mathematics

Based on previous experiences with college algebra students at the community college, Mrs. A believed that most students enrolled in the course were apprehensive about the class and mathematics in general (I-T-2). She wanted to know about this group of students and how they felt about math and math teachers so an e-mail assignment given the first day of class included six questions and an addendum. Students' responses to the questions are displayed in Table 4.

The following two questions related to feelings and the addendum encouraged optional additional responses: "How do you feel about math? How do you feel about math teachers? Be sure to include any information that you think I might need in order to be a better teacher for you" (D-C-1). She also wanted to know how the course fit in with their educational plans and goals. Three questions related to the course placement in their educational career, what they were going to do with the course credit, and what degree they were seeking. One question requested information about how students felt about graphing calculators. Eight of the eleven students responded to the e-mail assignment. Of the eight responses, three students indicated that they had a difficult time with math or algebra, two students felt okay with the subject, and three students liked it.

Table 4

Students' Responses to Questions about Math and Math Teachers

Student 1: I did take some remedial math courses then that put me at the level prepared to enter college algebra. I used to be very intimidated by the whole idea of algebra. I am very good at basic mathematics but tend to get confused with algebra. I have always felt very comfortable around math teachers and have met some wonderful ones who have tried to ease my anxiety but I always felt they know a language that I just haven't been able to fully comprehend. . . .I hope to tap into that language and come away from the class feeling quite competent.

Student 3: I like mathematics but sometimes it does not like me. I like math teachers.

Student 4: I don't hate math, but I don't just love math either. I like math teacher just as much as any other teacher.

Student 6: I have been in and out of math classes since 1991. I have had a struggle with math for as long as I can remember. This will be my 4th time to take College Algebra! I have always dropped to avoid getting an "F" on my transcript. . . I was told that I have a math disability called Dsycalculis . . . although I have seen it spelled different ways! I went to a testing center in Dallas last year. He asked a lot of questions and I took a bunch of tests. I told him that as far back as I can remember I have had math trouble. . . My earliest memory was first grade! I remember sitting at my desk with my "play" money and not having a clue as to what to do with! To this day I cannot count back change!! I feel a little intimidated by math because it has always been the force keeping me from completing by degree! I hope and pray that this time it is different! My teachers, in general, have been helpful. I did not find out about my dyscalculia until last year, so a few of the teachers that I have had have accused me of mot trying and just being difficult! My feelings in general about the teachers are positive! Since I have been open with them about my issue, they have been really helpful and supportive! . . . I just want to let you know that I enjoyed your class today and I have a positive feeling that this will be the year that I finally pass!!

Student 7: Math is my favorite subject. . .

Student 8: Thanks for the class today and the encouragement you gave me. This is my first college math class, and I am still in high school. . . . I'm not for sure that I can handle the material in the class, but I feel if I take it one class at a time I can get through the book well. In my math classes in high school, all my classes were done on the computer. I watched video clips of an instructor working example problems for that lesson. After doing 6-8 practice problems, I would do 20-30 on paper. The thing I liked most about doing my classes on the computer was the ability to watch the instructor do the problems as many times as I needed to. . . . Thank you for asking for this information, I think it's a great idea.

Student 9: My hardest subject probably. I didn't have a good experience with my math teachers in high school. . . .What I believe helps me the most in a math class is A LOT of examples, so that would be how you could be a better teacher for me.

Student 11: Math is not my favorite thing but I seem to be getting more competent at it. I like math teachers as long as they teach, seems like most math classes I'm teaching myself.

Feelings about Calculators

One of Mrs. A's class goals was to promote students' use of the graphing calculator. Previous experiences with other college algebra classes led her to expect a number of the students would be inexperienced with graphing calculators or apprehensive about using them (I-T-1). To find out about how students felt about using graphing calculators, students were to respond to the following question in an e-mail assignment given the first day of class: "How do you feel about graphing calculators"? Students' responses to the questions are provided in Table 5 (R-A-1). The range of emotional responses to the calculator question was wide and included the following: five students either hoped or felt they would be okay, one student was kind of scared, one student was undecided, and one student loved them. Table 5 will be discussed in more detail in Chapter V.

Concern about students' comfort levels using the graphing calculator was expressed the first day on class on her lesson plan questionnaire. In response to the open ended question, *Concerns related to GC use,* she wrote: "varied comfort levels among students" (Q-T-1). Strategies used to help students become more comfortable using the calculator when new keystrokes or techniques were introduced included providing explicit instructions on how and when to use the tool, written instructions on the keystroke sequences necessary to perform the techniques, guided practices during class, and specific homework assignments.

Additionally, students were encouraged to ask questions about calculator use during class lessons and tests. Asking questions about the graphing calculator was encouraged starting the first day of class (O-L-1). During Class 5, one student asked if the graphing calculator's instructional manual could be used during the test in case he/she needed reminding about the keystrokes necessary to perform a technique. Mrs. A replied: "Yes, you may use the book but the best thing to do is to ask me" (O-L-5).

Table 5
Students' Responses to Feelings about Graphing Calculators

Student 1: I am not very familiar with graphing calculators but technology does not intimidate me so I think I will be okay.
Student 3: I have never used a graphing calculator in my life so I am kind of scared.
Student 4: I don't know much about graphing calculators to decide how I feel.
Student 6: Graphing calculators are a complete puzzle!! I have used one before but not a lot. It was in the College Algebra class before this one and I dropped it before we really got into it. I hope to be able to understand it better! I think it could be a really useful tool!
Student 7: I love the graphing calculators.
Student 8: At the moment, I don't have one of the required graphing calculators for the class. I'm certain that I will either be borrowing one or will buy one before the next class though. I feel fairly confident that once I get a graphing calculator, I'll be able to use it well.
Student 9: Graphing calculators are very helpful but I do not know how to do much on them.
Student 11: I don't know anything about graphic calculators but I tend to be better with gadgets I hope it will increase my ability to do math.

Feeling Safe

Creating a classroom climate in which students felt safe to take risks involved in learning was crucial to Mrs. A. Her concern about students' feelings and the impact such emotions have on learning was expressed in the following comment she wrote on a lesson plan questionnaire: "Students will NEVER learn to use math or technology until they feel academically 'safe'" (Q-T-3). Concern for how the students were feeling about whatever they were doing in class was evident in several ways. She seemed to be able to read students' faces and could instinctively sense when students were feeling confused or frustrated. When this happened, she would either say the students' name or address the class as a whole: "You look confused. Okay, let me explain it a different way." During Class 25, she looked around the class and said: "You all look like you have been overloaded with information. Let's stop now and continue next class" (O-L-22). During formative or summative assessments, she would walk around the room and ask students individually how they were doing. Being sensitive to students' feelings was one way Mrs. A strove to create a safe environment and to show students that she cared about them and their learning.

<u>Overcoming Anxiety</u>

Mrs. A's efforts to establish good teacher and student relationships and to reduce students' stress were noticed by her administrator. The college dean made the following comment on a faculty appraisal: "(Mrs. A) establishes a good rapport with her students and helps them overcome anxieties they may have about math" (R-E-1). The dean also noticed that she helped students on her own time.

At another section of the appraisal the dean writes: "(Mrs. A) goes above and beyond the normal expectations of faculty members with regards to helping students. She holds extra study sessions and even comes in on the weekend to help her students. She has a great sense of obligation to get her students through the course material" (R-E-1). His comments are an indication of how Mrs. A helps students overcome their math anxieties by offering them extra opportunities to learn and become comfortable with the required material. Mrs. A also gives test-taking and study tips during seven classes to help students reduce their anxieties.

Keeping Stress Reduced

Mrs. A did not want anything to add to students' stress or to make them feel reluctant to participate in class activities. Therefore, in regard to this study, she requested that video and audio taping not be used because she felt the presence of the equipment may make students self-conscious or reluctant about participating in class activities. Additionally, she felt a pre-test would "freak out" some of the students so a pre-test and post-test was not used for the study (I-T-1; I-T-2).

Aspects of Representation Systems of Class Environments

Aspects of the class environment representation system that are described include class interactions, graphing calculator use, and a community of learners.

Class Interactions

Mrs. A strove to create a class atmosphere where students felt safe enough to participate in class interactions and to risk asking questions regarding math or the calculator. For example, in preparation for a guided inquiry instructional lesson for Class 3, the "Car Wash Problem Activity," she told the students: "When I ask a question, I want you to respond; do not be concerned with raising your hands" (O-L-3). This seemed to make the atmosphere in the class more relaxed and less formal as compared to a class where students raised their hands to be recognized before speaking. Students' continued to respond to whole class questions this way throughout the semester.

To promote the initiation of students' questions, Mrs. A writes: "I try to foster a 'safe' math environment so students feel they can ask math questions <u>as well as</u> technology questions" (Q-T-3). Likewise, in efforts to reduce students' stress about whether or not their responses in class dialogues are right or wrong, Mrs. A implores, "If I ask how you thought about a problem, there can be no wrong answers; I want to know what you think" (O-L-2). Mrs. A indicated her respect for students and their thinking by encouraging them to ask questions and to respond to her inquiries.

<u>Graphing Calculator Use</u>

Whenever graphing calculators were used in class, the instructor projected her calculator's viewing screen on the wall or board by means of the tool's viewing panel on an overhead projector. The external visual display provided a shared reference for instruction and discourse. The panel also provided an image for students to view as they followed along on their own calculators. Likewise, student's own calculators served as visual references for collaborations among students.

<u>Community of Learners</u>

Before using inquiry techniques for teaching during a mathematical modeling activity during Class 3, Mrs. A gave the following talk imploring students to strive to become a community of learners:

> At a university a college algebra class would be in a lecture hall with a hundred or more students. This is a community college so our classes are smaller. We can do things that can't be done in larger classes. Together we can be a community of learners by sharing with each other and helping each other. I want you to not

only be responsible for your own learning but to take responsibility for the learning of the students sitting around you (O-L-3).

Mrs. A proceeded to give the students examples of how they could work together to become this community.

Aspects of Representation Systems of Mathematics Structure and Cognition

Aspects of the mathematics structure and cognition representation systems discussed include instructional objectives, mathematical understandings, and graphing calculator use.

Instructional Objectives

The instructor's course syllabus outlined the instructional objectives to be taught and the corresponding class dates (D-C-1). An overview of the objectives was discussed with the students during orientation the first day of class (O-L-1).

Mathematical Understandings

An overview of the concepts and skills to be learned during the class was given when the instructor went over the course syllabus during orientation (O-L-1). Mrs. A's expectations for students to learn and understand the concepts and skills that were taught during instructional classes were exhibited in her use of informal assessments.

Graphing Calculator Use

Mrs. A explicitly expressed her expectations for students to get used to using the graphing calculators. At the beginning of class 2, Mrs. A asked:

> Did anyone walk to class today? (Students chuckled.) If we all used technology to get to class, let's get used to using technology in class. There are lots of ways

to solve math problems. Go ahead and use your preferred way but then also get used to using the graphing calculator (O-L-2).

Although students were to use their choice of solution strategies, they were expected to learn and encouraged to practice graphing calculator approaches. Mrs. A expectations regarding students graphing calculator use was emphasized the first day of class. The first class meeting has been described in detail because of the precedence set related to Mrs. A's expectations for students' behavior and graphing calculator use.

Orientation to Class and the Graphing Calculator

The graphing calculator's role as an integrated part of the course was emphasized the first day of class. The instructor was straightforward in communicating to students the integral role that the graphing calculator would have throughout the course as a tool to enhance both teaching and learning. Detailed descriptions are given concerning this class because the expectations conveyed concerning graphing calculator use and class participation set the tone that was followed the rest of the semester related to the following subjects: student's graphing calculators, instructor's graphing calculator viewing panel, instructor's handouts, self-directing and self-checking graphing calculator activities, asking questions, class participation, and homework.

Teacher expectations for students' behavior when using the graphing calculator were explicitly expressed during this class and listed in Table 6. Of the twelve classroom norms described in Section II, nine were initially expressed during this initial graphing calculator activity and will be discussed in more detail in Chapter V. During the orientation class, the importance of having an approved graphing calculator for class use

Table 6

Teacher Expectations Related to Graphing Calculator Use Introduced on the First Day of Class

Number of Expectations	Teacher Expectations
1	Students were expected to bring an approved graphing calculator to class.
2	Students were expected to do what the teacher is doing on their own calculator during calculator activities
3	Students were expected to use the teacher's calculator's viewing screen projection as an external visual reference
4	Students were expected to use the self-directing and self-checking calculator activities for homework practice
5	Students were expected to stop the teacher and ask questions when they got lost or didn't understand what they are doing on the calculator
6	Students were expected to understand why they were doing certain keystrokes, what was happening as a result, and what the images on the screen represented.
7	Students were expected to understand how the multiple representations were connected to each other.
8	Students were expected to express how they were doing and feeling about using the calculator in response to teacher requests
9	Students' could expect the teacher to informally assess their use and understanding of the calculator during walk around the classroom observations.

was stressed by the instructor. Calculators recommended for class use were specified in the instructor's "Welcome" page attached to the course syllabus and included one of the following graphing calculators: TI-83, TI-83+, TI-83 Silver, TI-84 or TI-84 Silver. Students were told that if they chose to use another type of graphing calculator, they were responsible for figuring out the how to use it. Then, the instructor checked each calculator brought to class to make sure it was appropriate. One student had left her calculator in the car and was asked to go and get it. Another student was told that the four function calculator that she had brought to class was not appropriate and was loaned one of the instructor's calculators to use during that class. Other students paired up with someone who had a graphing calculator with them or borrowed one of the instructor's calculators so they could participate in the class activity (O-L-1).

In addition to the syllabus with the attached “Welcome” sheet, the following three handouts were passed out: a study guide, a TI 83 Menu Map, and a graphing calculator activity. The study guide for chapter 1 listed vocabulary to learn, exercises to complete from the text book, and stressed the learning of two graphing calculator based methods of solving equations explained in appendix 4. Five methods of solving quadratic equations were listed with the graphing calculator method being noted as “our method of preference☺”. A TI 83 Menu Map was handed out on colored paper for the students to use as a reference when they wanted to know where certain keys or commands were on the calculator. The third handout was a graphing calculator activity that Mrs. A retrieved from an internet site (D-G-2).

The graphing calculator orientation activity featured the tool’s capacity to quickly access multiple representations of a quadratic function and provided step by step directions for using the calculator with screen shots providing visual support. The activity presented the use of a quadratic function to model the situation of a wadded piece of paper being thrown from hand to hand. The activity served the following purposes: introduced the use of the graphing calculator as a teaching and learning tool; provided directions for the keystrokes to be used; introduced the use of the instructor’s overhead graphing calculator’s viewing panel; emphasized making connections between multiple representations; and stressed the importance of understanding the meaning of the representations.

The activity focused on making connections between the written, the concrete, the pictorial, the algebraic, the numerical, and the graphical representations. Mrs. A provided additional visual support by using an overhead graphing calculator's viewing panel to project her calculator's screen on the wall for the students to view as they followed along on their calculators. She used the poster of the graphing calculator displayed on the front wall to show students the location of the calculator keys they needed to use (O-L-1).

Students were instructed to stop her if they got lost using the calculator or did not understand her explanation of the different representations being viewed. When students requested help with the graphing calculator, Mrs. A. came and told them the keys strokes to use and where the keys were. She did not touch the calculator but had the student do the key strokes (O-L-1).

Mrs. A checked students engagement and how they felt about the activity. After each step in the task she came down the aisle to check with each student to make sure they were okay with everything. She stated her concerns related to graphing calculator use as "varied comfort levels among students" (Q-T-1), indicating her attention to affect aspects involving in learning.

The instructor's use of the graphing calculator view screen served two purposes: as an external reference for students to compare their screens; and as an external reference to facilitate social interactions. Mrs. A used the projected image to talk to the students about the what, how, and why of what they were seeing (O-L-1).

The students were assigned to go over the graphing activity again for homework to become familiar with the key strokes necessary to view and use the different representations. Students were told to focus on understanding what they were doing and seeing when using their calculators. Mrs. A implored, “I don’t want you to just **do** the activity for homework. I want you to think about why you are doing the keystrokes and what is happening as a result. I want you to understand what the images on the screens represent, what they mean, and how they are related to each other” (O-L-1). The expectations for graphing calculator use expressed during orientation eventually became part of the classroom norms.

At the end of class, students filled out the researcher’s student lesson questionnaire form. Table 7 summarizes the students’ self-reported responses to the use of the graphing calculator and related issues (Q-S-1). The questionnaire responses indicated that 88% of the students felt the graphing calculator enhanced their understanding of the lesson and 75% of the students felt the tool facilitated class interaction that enhanced their understanding of the mathematics related to the lesson.

Table 7
Summary of Students’ Questionnaire Responses to the Use of the Graphing Calculator on the First Day of Class

Questionnaire Question	Percent of Responses Very Beneficial	Percent of Responses Moderately Beneficial	Percent of Responses Not Beneficial
How beneficial was the use of the graphing calculator for enhancing your understanding of today’s lesson?	88%	12%	0%
How beneficial was the graphing calculator in stimulating or supporting discussion and collaboration that enhanced your understanding of the mathematics related to today’s lesson?	75%	25%	0%
How beneficial was the use of the graphing calculator overhead projector screen in helping you follow along during today’s lesson?	100%	0%	0%

Student 3 responded moderately beneficial to both questions related to enhancing understanding and added later in the questionnaire that she "already understood" the lesson's topics. However, all student responses were favorable to the use of the graphing calculator with the visual support of the graphing calculator viewing screen receiving very beneficial from all students. The graphing calculator orientation on the first day of class helped to set the tone for its use as an instructional and learning tool throughout the semester.

Development of Classroom Norms

For this study, the identification of classroom norms included the expectations and/or behaviors that became routine during the regular class periods. An action was considered routine if it was observed in multiple class sessions. The constant comparative method was used to identify recorded behaviors from the descriptive scripting and field notes leading to the naming of norms that were later grouped into four categories. The identified classroom norms were supported by using a triangulation of data sources and methods including student questionnaires, the teacher's lesson plan questionnaire, informal interview, and documents.

Descriptions of how the instructor used the graphing calculator to promote her goals or objectives are given in selected episodes of class activities that include students' reactions to her expectations. Supporting data indicates the instructor's proactive approach in using the graphing calculator to stimulate classroom participation and to enhance students' understanding. A summary of classroom norms for the 23 instructional lessons is given in Table 8. Behaviors promoted or supported by use of the graphing calculator are listed below the appropriate norm. The norm descriptions are separated into the following four major categories: organizational and instructional arrangements, members' interactions, sociomathematical agreements, and affective aspects.

Table 8
Summary of Classroom Norms and Promoted Behaviors with Graphing Calculator Use

Norm Number	Norm Description
	Organizational Features
1	Required materials Students brought an approved GC to each class session
2	Availability of materials The GC was available for students' use at all times except three quizzes
3	Visual supports Use of a TI 84 Poster, handouts, and a calculator viewing panel supported students' use of graphing calculator
4	Homework assignments Certain assignments required the use of the GC for exploring and practicing skills or concepts
	Members Interactions
5	Student participation Students' hand-on interactions with the graphing calculator raised their level of class participation
6	Focus on understanding The instructor used informal assessments to check students' understanding when using the graphing calculator
7	Ask questions and request help Certain activities using the graphing calculator promoted questions and requests for help
8	Collaboration and support Students helped each other with graphing calculator related issues
	Sociomathematical Agreements
9	Use multiple representations and their linkages The graphing calculator facilitated the use of multiple representations for some topics
10	Use preferred solution approaches and methods Graphing calculator solution approaches and methods provided an alternative to traditional approaches
11	Use the graphing calculator Use of the graphing calculator was encouraged for some topics and skills
	Affective Aspects
12	Respect for other individual's feelings, comments, and ideas: Students responded to questions about how they were doing when using the graphing calculator

Norm 1: Required Materials

Required Materials

Students are required to bring to class their course text book, an approved graphing calculator, and appropriate handouts. The handouts are provided to support students' learning and use of the graphing calculator. The following materials were either created or put together for students' use by Mrs. A: study guides and homework assignments, practice tests, vocabulary lists, chapter summaries, graphing calculator activities, matching activities, topic packet, and blank coordinate grids. Some of the exercises from the text book were also copied so students would not have to write in their book when completing those assignments.

All students had the class text book and their graphing calculators by the fourth day of class. Students regularly brought their text books and graphing calculators to lesson sessions and their calculators for major assessment sessions with one exception. During Class 13 when the instructional focus included the use of the text book, Mrs. A noticed that one of the students did not have her book and that the person who usually set beside her was not present. The student remarked that she was running late after work and didn't have time to go home to get her stuff for class. Mrs. A said, "I don't think (name omitted) would mind sharing her text book with you, would you?" The student responded, "Sure." The student without her supplies left her seat to sit next to this student (O-L-12).

Approved Graphing Calculators

The importance of having an approved graphing calculator stressed on the first day of class was re-instituted the next three class periods. During the second class, Mrs. A asked how students were doing in getting a calculator to use for class. The instructor checked each student to make sure they had an appropriate graphing calculator the third class period. One student did not have a calculator yet so she was loaned one to use in class. A student calculator check by the instructor the fourth class period indicated that all the students had a calculator that passed her inspection. From then on, the students participating in this study brought their calculators with them to all class periods with one exception. One student did not have her calculator for Class 13 (O-L-12).

Norm 2: The Availability of Materials

The availability of materials for students use varied during the semester depending on the focus of the class session. For instructional activities, the course text book, handouts, notes, and calculator were available for student's use at all times. For assessments, accessibility to the supplies differed according to the purpose of the quiz or test and are described after the instructional lesson norms are presented.

Norm 3: Visual Supports

Materials Used

A variety of materials were used to provide visual representations to support the verbal delivery during instruction. The materials incorporated the use of recording, static, and interactive media. Recording media used included writing on the white board or transparencies on an overhead projector. Static media used included printed materials such as text book, handouts, transparencies, and posters. Interactive media used involved the use of a graphing calculator attached to a viewing panel on an overhead projector. The use of this technology permitted students to see an image of the instructor's calculator screen projected on the wall and was used whenever the instructor used her TI-84 graphing calculator.

Graphing Calculator Viewing Panel

Whenever Mrs. A used her TI-84 overhead graphing calculator it was connected it to a viewing panel placed on an overhead projector to project her calculator screen image on the wall or board for the class members to see. The use of the graphing calculator viewing panel served three important purposes. As an external reference for instruction, the projected visual was used to talk to students about the image on the screen, why it was there, and what the representation meant.

The visual provided a way for students to check that they were keying in the correct key stroke sequences and that they were obtaining a similar screen. The image also provided a shared reference facilitating questions and discussions. The viewing panel was used in all 21 classes in which the Mrs. A used the graphing calculator. The viewing panel was also used in combination with other materials.

During Classes 20 and 21, the graph on the calculator screen was projected onto the white board and different colored dry erase markers were used to identify and name significant points and parts of the graph. Secondly, the projected image served as an external reference for students to use in following along with the instructor and to check the accuracy of their screen with the projected image.

Norm 4: Homework Assignments

Homework Assignments

Homework assignments were included in the chapter study guide handouts. The purposes of the work varied and included the following: skill practice, exploration activities, reading assignments, practice tests, and graphing calculator exercises. Answers to the problem exercises from the text were given at the back of the book. Answers to the practice tests were given at the end of the handout.

The homework assignments were not graded or collected but the instructor expected them to complete the assignments and explicitly reminded students to do their homework during lessons throughout the semester. Students were expected to initiate questions about homework if they had problems with the exercises. Questions related to homework problems or reminders to do the homework occurred during 13 of the 22 instructional classes.

Graphing Calculator Homework

Students could use the calculator for any of their homework. However, there were four assignments specifically designed for students use with the calculator. Three of the assignments were to help students become familiar with the keystrokes and sequences to be used in the next lesson. The other assignment was an exploratory exercise.

The first homework assignment included going over the multiple representations activity completed in class 1 and learning two graphing calculator methods for solving equations given in the appendix of the text book (O-L-1). Part of the homework assignment to be completed before Class 4 included going through a self-directing and self-checking graphing calculator activity. The handout included the keystrokes and screen shots necessary to support students' use of the graphing calculator to complete a stat plot, to analyze data, and to formulate regression lines (O-L-3).

Before Class 11, students were to go through the teacher created exploratory activity on transformations of parent graphs (O-L-11). Before class 21, students were to go though the teacher created handout on matrices and to familiarize themselves with the keystrokes and sequences necessary to solve matrices on the calculator.

Norm 5: Student Participation

Informal Assessments

Mrs. A's implicit expectation regarding students' participation is implied in her use of formative assessments such as observations, questioning techniques, and discussions in the 23 lessons. Expectations regarding students' participation in following along on their calculators as the teacher demonstrate the use of the tool during class activities were implied through teacher's actions the first day of class (O-L-1).

Graphing Calculator Use

All students used the graphing calculator to follow along with the instructor during the 22 instructional lessons that used the calculator with two exceptions. One student did not have her calculator for Class 13 and one student just observed how the calculator was used during Class 26 instead of following along and manipulating the tool (O-L-12; O-L-23). Students' behaviors in using the graphing calculator indicate that the students responded to the instructor's expectations for class participation.

Scaffolding Levels

Means computed from the analysis of M-SCOPS data resulted in the identification of four different types of scaffolding levels and the percentage of time the levels were used during lessons: direct instruction, 24%; teacher-directed discussions, 8%; group work, 61%; small group work, 6%; and individual open-ended work, 1%. The mean percentage of time that instructional scaffolding levels were used to promote interactive student engagement during the course was 68%.

Students' Engagement

Students were expected to be engaged in their peer's questions and discussions about homework problems by listening to and attempting to understand other members' thoughts. During a discussion about a homework problem, the instructor asked two students what they would do next even though they did not ask the question (O-L-3).

Norm 6: Focus on Understanding

Both informal and formal assessments were used during the course. Students were expected to learn each lesson's skills and concepts. Even though student understanding is an internal representation, it may be inferred from student's external productions. The instructor used a variety of formative assessments to monitor students' engagement, understanding, and emotional states throughout the course. Strategies used included observation, questioning techniques, discussions, listening during group work, checking students' work, checking students' calculator screens, and peer checking.

Informal Assessments

The formal assessments included 6 quizzes, 4 tests, and a final exam. For the 4 tests and the exam, students were able to use their graphing calculators and handwritten notes they had made on an 8” x 10 ½” sheet of paper. Five of the 6 quizzes were given at the beginning of regular instructional days. One quiz was a take home assessment that consisted of a problem involving the use of scatter plots, regression equations, and data analysis and evaluation. Students’ quiz problems were different but assessed similar skills. Students were trusted to do the work themselves but were allowed to their other class resources as references.

The graphing calculator was available for students’ use for all but 3 of the quizzes. For some topics, such as multiple representations of parent functions, transformation of functions, and properties of logarithms, use of the graphing calculator could mask students’ understanding of the concept. Therefore, the graphing calculator was not permitted on the three quizzes that assessed students’ understanding of these topics.

Calculator Use and Enhanced Understanding

Mrs. A wanted students to realize that the use of the graphing calculator offered opportunities for students to learn and interact with mathematical ideas in new and dynamic ways. At the beginning of Class 10, Mrs. A handed out an exploratory graphing calculator activity that she had created on transformations of parent graphs. She went over what she wanted the students to do and demonstrated an example on the board. The assignment was to be brought back completed to the next class. She said. “You can sit here and do it or take it home and do it, just as long as it gets completed before class on Wednesday" (O-L-9). Although there was not any accountability associated with students' completion of the assignment, the intended task goal was for students to explore the connections between the changes in the equations and the resulting graphs leading to a generalization of transformation rules.

Although Mrs. A offered to help anyone who wanted help with the activity, none of the students stayed after class. Students were to take responsibility for completing the task using the activity handout as their guide and their graphing calculators as their personal instructional scaffolding tools. If the assignment had been completed in class, according to the M-SCOPS coding scheme, the complexity level of representational scaffolding for this activity would have been coded as a 6 which is the highest level in the student action category codes requiring students to generalize.

The instruction on transformations during Class 11 focused on helping students connect the types of transformation completed in the homework activity to the transformation rules for functions. The students' focus was drawn from their dependence of the visual calculator display to developing an abstract understanding of the transformational rules and concepts; therefore, the calculator was only used 10% of the time for this class. Mrs. A implored: "I want you to understand that the calculator is a tool to help you explore and understand concepts; before the calculator we had to make up pages of graphs to help students understand transformations" (O-L-10). During this activity, students were given opportunities to explore transformational concepts and to generalize the transformational rules on their own or with Mrs. A's assistance. Then she wanted students to conceptually understand the rules and how they worked without the support of the calculator.

Students had been informed during Class 10 that they would not be able to use the graphing calculator for the quiz on Class 12 that assessed their understanding of the transformational rules. Mrs. A made the following suggestion to students on how to study for the quiz: "Write down an equation using little numbers, describe how the parent graph is being transformed, and then check your answer on the graphing calculator" (O-L-10). This study tip encouraged students to practice using the dynamic interactive features of the calculator to deepen their understanding of the concept.

Understanding Underlying Concepts

Mrs. A wanted students to understand the underlying concepts of the representations being created with the calculator. At the beginning of Class 16 she entered the room, wrote, $y = 2^x$ on the board, sketched a table of values with domains of a negative 3 to a positive 4, and instructed students to complete the table and plot a graph using the graph paper that was included in their chapter 5 study guide packet. Without any more direction, she left the class. Students talked among themselves about how to do the task since they had not received instruction for this type of function.

When Mrs. A arrived back in class 5 minutes later, she asked each student how they approached the problem. All students said they used the calculator. After hearing this, Mrs. A proceeded to complete the table by hand explaining her thinking as she went and receiving input from students when she asked questions. She showed students how the values in the table represented repeated multiplication, a characteristic of exponential functions. The episode indicated that all students chose to use the calculator on their own for this open-ended exploratory task being able to transfer their general knowledge of characteristics of functions and calculator use to a function not previously studied. Most importantly, the vignette indicated that Mrs. A wanted students to understand the underlying concepts involved in the representations being created by the calculator, how the different representations were connected, and how the representations were related to other mathematical concepts.

Grades and Comments

Although student understanding is not externally observable, their understanding of the course material can be inferred through their grades and the course evaluation forma. The following final grades were received by students for the course: nine students received A's, one student received a B, and one student received a C. Eight students completed the college's course evaluation survey. The following open form question was on the form: *What did you find most helpful about this course and what did you learn?* Of the seven students who responded to the question, five comments related to understanding the material. Their answers indicate that they felt Mrs. A instructional approaches helped them understand the concepts being taught. Their responses are listed in Table 9.

Several strategies were used by the instructor to promote students' efficient utilization of the graphing calculator for the purposes of enhancing their understanding of mathematics. Model-based activities were used to orient students to commonly used features of the calculator starting with the first day of class. Supplemental handouts

Table 9
Anonymous Students' Responses to the Question: What did you find most helpful about this course and what did you learn?

Number	Students' Responses
1	The fact that I actually understood everything she taught us and she made sure I did.
2	The way (Mrs. A) teachers. She makes it easy to understand!
3	I feel I have gotten a real grasp for Algebra from this class.
4	I learned a lot of things I did not know and things that will be helpful for classes in the future.
5	The way the material was explained.

were provided to support students' self-directed and self-checked use of the tool during lessons and independent practice for homework assignments. Direct instruction was given regarding how, when, and why the graphing calculator was being used. Guided practices with frequent informal assessments were used by Mrs. A and peer checking was used by the students.

Students' use of the calculator was supported by the external visual projection of the instructor's calculator screen. The projected calculator image was used to facilitate instruction, to provide visual support for students, and to stimulate class interactions. Students were actively engaged during activities by using their calculators as demonstrated by the instructor. Students asked questions, participated in discussions, collaborated with each other, and showed respect for each others' solution approaches. Students' independent use of the tool was exhibited during major assessments.

Norm 7: Students Initiated Questions

Students were encouraged to ask questions when they did not understand something or needed help. During instruction on how to determine the slope value from a linear graph, one student blurted out: "I have no idea what you are doing" (O-L-4).

Mrs. A stopped what she was doing and went to help her while the other students worked on another problem. Students initiated questions during 13 of the 23 instructional classes. A comparison of class segments in which the graphing calculator was used and questions were asked indicated that the graphing calculator was being used in 10 of the 13 classes where students initiated questions.

Norm 8: Collaboration and Support

Collaboration

Students are encouraged to look out for each other and help each other. During Class 2 she put the class into two groups and gave them two different problems to work on. Students were encouraged to ask each other "how do you think about it" so they could understand how the other students approached the problem and the methods they used to solve it (O-L-2). Throughout the semester, students listened to other students' questions and comments and responded as appropriate for the situation.

Ask for Help

At the beginning of the third day of class, Mrs. A asked if there were any questions about the homework. One student requested help with a problem using a graphing calculator approach to determine the solution. After the instructor demonstrated how to find the intersection points between the graphs of a parabola and a line, one student asked for clarification on how to find the intersection points. She asked the student, "Who would you ask to help you with this problem if you couldn't ask me?" The student asked another student to answer the question for her. The student answered the question correctly. Mrs. A responded, "(Name of student deleted) did a really good job of answering your question. I think you chose very well. Yeh (name of second student)! (Name of first student) really had a good resource to get help. Other resources that you can use besides asking someone during class is to get someone's e-mail or get a study buddy" (O-L-3).

Check Your Neighbor

During certain activities, Mrs. A gives the students time to either help or check each others' work. She says, "Do this problem then check with your neighbor . . ." During five classes she waited for students to check with their class mates to make sure everyone understood what they are doing on the calculator. During Class 22 she told them to work on a problem and without saying anything about checking with their neighbor, the students initiated the action themselves and started talking to those students nearby. Students' checking their neighbors' work without the teacher's prompting indicates that the behavior had become a normal part of their class routine.

Graphing Calculator Support

Having students check with their neighbor was a strategy Mrs. A used to address an issue about graphing calculator use. One of the instructional concerns Mrs. A had about using the graphing calculators was "not enough time to get to everybody" to check to make sure students were doing the keystrokes correctly and that they were okay with the procedure (Q-T-3). Having students assist other class members helped to alleviate that concern. Mrs. A wrote the following reflective note on a lesson plan questionnaire: "Many students are now feeling confident enough to help their fellow classmates with this technology. Yea" (Q-T-3)! Such a comment indicated that she rejoiced to see her students reaching out to assist and support other students with their graphing calculator use.

Norm 9: Use of Multiple Representations and Their Linkages

<u>Multiple Representations</u>

The use of multiple representations was an essential part of the course. The importance of understanding different ways to look at a mathematical idea and the connections between them was emphasized all 23 instructional sessions.

<u>Multiple Representation Activity</u>

During Class 3, the concept of multiple representations was developed using Mrs. A's contrived car wash activity and an inquiry instructional approach. The problem was written on the board and students were told to take very good notes. Mrs. A collected and used information from each student to use in the activity. The data was used to build a table, to sketch a graph, and to derive an equation that modeled the situation.

The graphing calculator was used to verify the work completed by hand after the derived equation was rewritten into a form the calculator could use. Members then engaged in a discussion on how to use the graphing calculator and how powerful the algebraic equation was that by entering it into the y= menu the calculator automatically built table of values and created a graph (O-L-3).

<u>Understanding the Different Representations</u>

Mrs. A stressed the importance of understanding the verbal, table, equation, and graph as different representations of the problem. She implored, "All four representations mean the same thing. You must learn to make the associations between them. Learn this very carefully! If the point is on the graph it is a solution, in a table it might be impossible to list all solutions. The graph has all the solutions; the table may just show representative points" (O-L-3).

Connections among Representations Using the Calculator

The graphing calculator was used to emphasize the connections among representations. Pressing the trace key when viewing a function's graph displays the equation at the top left of the screen and the coordinates of the point where the cursor is located on the graph. Figure 1 provides a calculator screen display of simultaneous representations and offers students a visual approach to making connections among the function's representations.

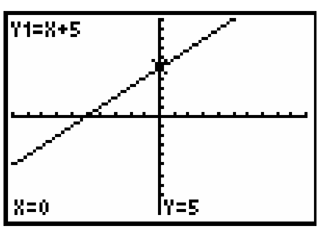


Figure 1. Graphing calculator screen shot display of an equation, a line, and an ordered pair, respectively representative of symbolic, graphic, and numeric aspects of a linear function.

Norm 10: Varied Solution Methods and Approaches Were Valued

Varied Approaches

Students were asked to explain how they thought about the problem or what they did to solve the problem. During Class 2 students were taught two graphical approaches to solving linear and quadratic equations on the calculator as alternatives to the algebraic methods they learned in high school. After letting students individually practice solving a few problems she led a discussion about a problem after stating, "There is no one set right way to do the problem." During the discussion, she asks students, "Is this how you would attack the problem?" She wanted to know all the different methods or approaches students used to solve the problem and how they used the calculator (O-L-2).

Understanding Individual's Approaches

During Class 5, a student asked a question about a problem on the practice test. Mrs. A asks the student, "How did you try to do it?" I inferred that she was trying to understand how the student approached the problem so she could build on the student's understanding or help clear up a misunderstanding. When discussing another problem in the same class she comments: "It does not matter how you chose to do the problem" (O-L-5). When demonstrating how to work a problem for the class that has multiple solution approaches she said: "This is how I approached the problem . . ." (O-L-8). Such instruction focuses students' attention on the processes of solving problems instead of concentrating on getting the correct answers.

Approximate Solutions as Opposed to Exact Answers

The use of graphical approaches for solving equations as opposed to algebraic methods sometimes results in approximate solutions as opposed to exact answers. Questions about such results lead to the following on the spot instruction. At the beginning of Class 3, Mrs. A asked if there were any questions over the homework assignment. A student wanted to know why the answer in the back of the text book was not the same solution received using the graphical approach taught in the previous class using the graphing calculator. To answer the question, Mrs. A explained the difference between an exact answer achieved using an algebraic method and a decimal approximation solution using a graphical approach. An exact answer with a radical term is determined using the quadratic formula but she accepts the decimal approximation achieved using the graphical method. Students were shown how to determine the decimal approximation of an exact answer with a radical term on their calculators (O-L-3). During Class 5, Mrs. A showed students how to match up their decimal approximation with an exact solution given in the answer choices of a multiple choice type problem (O-L-5).

Preferred Methods

Students were taught different approaches and methods for doing mathematics during the course. Students were encouraged to use the strategies that made the most sense to them. During an informal interview with a student after the last unit test (I-S-6); the researcher asked: “What things did this teacher do that helped you be successful?” The student replied,

> I think it is the way she explains things. She explains it different ways using different methods in a way that’s easy to understand. Then she let’s you decide which method to use to work the problems. She shows you how to use the calculator and let’s you decide if you want to use it or not (I-S-6).

Norm 11: Graphing Calculator Use

Visual and Numerical Approaches

The graphing calculator was used in 22 of the 23 instructional lessons. Visual solution approaches to functions using graphical and numerical approaches were presented during instruction of most functional concepts along with algebraic methods. However, during instruction on quadratic function solutions, Mrs. A remarked: "When I took this class years ago we spent a month on learning how to do this (completing the square) then we forgot **why** we were doing it. We are going to use the graphing calculator" (O-L-11).

The visual and numerical approaches offered students alternatives strategies to traditional methods using paper and pencil and permitted a focus on understanding the connections between and among the multiple representations of the concept itself without having to spend time learning the traditional algebraic methods required to access the representation desired for study.

Solving Polynomials

For solving polynomials with a degree of three or more, Mrs. A made the following comment:

> In high school I learned different methods for solving different types of problems. For us, we are going to use the graphing calculator to solve problems for polynomials greater then degree two. There is no a set way to solve these. The book takes many pages to show you how to do different methods. We are going to use the graphing calculator (O-L-12).

Modeling Problem Situations

The graphing calculator was used to work with concepts not easily accessible by hand. The use of the calculator offered opportunities for modeling problem situations, creating scatter plots, and performing regression analysis. The use of the calculating features of the tool facilitated problem solving, answering questions, and making predictions.

Computational Techniques

The graphing calculator was used for varied computational techniques. During the lesson on computing expressions with powers, Mrs. A asks, "How would you like to do that by hand?" A student replied, "I'd just take a zero" (O-L-14). After demonstrating to students how to multiply matrices by hand on the board, Mrs. A said, "You will not have to do this by hand, but you need to understand what the graphing calculator is doing" (O-L-18). The students were then showed how to use the tool to perform matrix operations and how to solve complex systems of equations using matrix approaches.

Verification of Work by Hand

Paper and pencil approaches to mathematical ideas were often used to develop students' understanding of a concept before the calculator was used. During a mathematical modeling activity in two variables, the car wash problem, and students had opportunities to develop their understanding of linear functions using paper and pencil methods then verified their work using the calculator. Later in the semester, during a lesson on intercepts, Mrs. A says, "We are going to do this without the graphing calculator to get the concept then we'll use the calculator."

After showing students how to use the calculator to determine intercepts, she explained, “What I am trying to tie together for you is that you should be able to answer the questions whether or not you are given a graph or if you are doing the graph on your graphing calculator” (O-L-7). The calculator was also used to verify the accuracy of the work completed by hand for solving linear and quadratic problems, determining slope, and creation of scatter plots.

Combined Topics and Graphing Calculator Use

The graphing calculator was used 50% of the instructional time during the course. However, a comparison of the mean percentages of time the calculator was used per unit indicated that the tool was used 86% of the time during the units 1 to unit 3 that covered functional concepts in chapter 1 through to chapter 5, and only 14% of the time during unit 4 that covered the concepts of matrices, conics, and sequences. Table 10 displays the mean percentages of time the graphing calculator was used during the four units and the main concepts studied for each unit according to the chapters in the course text book.

Table 10
Mean Percentages of Time of Graphing Calculator Use for Units

Audit Code	Chapter(s)	Concept	Percent of Time
M-V-1 to M-V-5	Chapter 1& 2	Linear & Quadratic Functions	67%
M-V-6 to M-V-12	Chapter 3&4	Functions & Transformation	43%
M-V-13 to M-V-17	Chapter 5	Inverse Functions	61%
M-V-18 to M-V-23	Chapters 6-8	Matrices, Conics, & Sequences	27%

Norm 12: Affective Aspects

E-Mail Assignment

Mrs. A expressed her concern about students in several ways. She strove to gain an understanding of both their overall feelings about math related issues as well as how they felt during activities in her class. She was also interested in how the college algebra course fit into their educational plans. On the first day of class students were given an e-mail assignment for homework. The questions they were asked to answer are displayed in Table 11 and were related to topics about their previous math classes and teachers, how the college algebra class fit into their educational plans, and how they felt about graphing calculators.

Table 11
E-Mail Homework Assignment Questions about Students' Mathematical Life

Question Number	Questions
1	Is this your first or last or somewhere in the middle math class to take?
2	How do you feel about math?
3	How do you feel about math teachers?
4	How do you feel about graphing calculators?
5	What do you hope to do with this math credit?
6	What degree are you seeking?
7	Be sure to include any information that you think I might need in order to be a better teacher for you.

Asking Questions

Mrs. A exhibited her concern about how students were handling classroom assignments or activities by physically approaching students at their seats and asking them how they were doing each class period.

Sensitivity to Students' Expressions

Sensitive to students' facial expressions or behaviors, she seemed to be able to sense when students were getting frustrated or overloaded with information. During Class 21, Mrs. A looked at the students and said, "You all look like you are getting overloaded with information. Let's stop here and continue the lesson on Wednesday" (O-L-18).

Course Evaluation Question

The following free response question was on the college's course evaluation form: *Would you recommend this instructor to another student? Please explain your answer.* Seven of the eight students responded to the question. Their answers indicate that they felt Mrs. A cared about them and wanted them to be successful in the course. Students' responses are displayed in Table 12.

Table 12
Anonymous Students' Responses to the Question: Would you recommend this instructor to another student? Please explain your answer

Number	Students' Responses
1	Definitely! She was the most helpful and best algebra teacher I have ever had.
2	Yes! She is great! I would not have passed without her! Thanks (Mrs. A)!
3	Yes! She is wonderful! She eases a person's math anxiety, is very thorough, and truly cares that her students succeed.
4	Yes. (Mrs. A) made everything understandable.
5	Yes. I would because of all the above info I gave.
6	Yes, she makes the subject easy to understand.
7	Yes, great teacher easy to work with.

Section II: Patterns of Graphing Calculator Use

Analyzed data was triangulated to derive finding two: the dynamic and interactive features of the graphing calculator facilitated the delivery of instruction at high cognitive levels during student interactive activities enabling access to, exploration of, and use of multiple representations for some mathematical concepts and solutions not easily attainable using traditional methods. Patterns of graphing calculator use were identified using constant comparison analysis of the field notes and the M-SCOPTS visual profiles from all 23 instructional sessions. Unit analysis of lessons revealed a positive connection between the mean percentage of time the graphing calculator was used and the receiving of complex cognitive representations. Mean analysis the M-SCOPS scripting data and visual profiles revealed that collaborative groups were used 68% of the instructional time indicating that student interactive instructional approaches were used the majority of the time during the course.

The value given to the graphing calculator as an essential tool for teaching and learning was evident through out the semester as both the teacher and the students had calculators on their desks ready to use whenever a situation warranted its use each class session. Although instruction and guided practice were given on how and when to use the calculator, instruction was never given in isolation but was always integrated into the teaching of the lesson. Use of the graphing calculator varied according to the topic and the lesson objective. When and how the calculator was used depended upon the perceived appropriateness of its use, the topic or skill being studied, and the class activity objectives. To facilitate analysis of the relationships between when the calculator was used, the topic or skill under consideration, and the purpose of class activities or tasks, the mathematical topics during the semester course were identified and separated into the following three different types of classroom sessions: instruction, review, and testing. The course consisted of, twenty-three lessons, four tests, one semester review, and one final exam for a total of 29 classes. Of the six quizzes given, five were completed before instructional lessons and one quiz was a take-home assessment. An overview of the class sessions, instructional topics, multiple representations, and graphing calculator use is displayed in Table 13.

Calculator Use and Functional Topics

The percentage of instructional time the calculator was used depended upon the topic being studied and the skills being addressed. However, the students' use of the calculator was under their control during major assessments. The graphing calculator was available at all times during all sessions except for three quizzes in which the use of the calculator could have masked students' understanding of the concept being assessed. The percentage of graphing calculator use was highest for functional concepts covered in chapters 1-5 and facilitated access to and use of multiple representations, use of numerical and graphical solution approaches, verification of work completed by hand, creation of scatter plots, data and regression analysis, exploration of topics to formulate generalizations, and problem solving of real life application situations.

Table 13

Summary of Class Sessions, Instructional Topics, Multiple Representations, and Graphing Calculator Use

Audit Code	Class Session Type	Session Topic	% of Time Calculator Used	% of Students Using Calculator for Tests
	Day 1-5	Class Orientation		
M-V-1	Instructional	Quadratic Functions Representations	100%	
		Linear/Quadratic Unit (Chapters 1-2)		
M-V-2	Instructional	Day 2: Solving equations	62%	
M-V-3	Instructional	Day 3: Intercepts & solutions	79%	
M-V-4	Instructional	Day 4: Slopes & lines	29%	
M-V-5	Instructional	Day 5: Data analysis & scatter plots	67%	
O-A-1	Day 6	Test 1 & Quiz, Chapters 1-2		100%
	Day 7-13	Functions/Transformations Unit (Chapters 3-4)		
M-V-6	Instructional	Day 7: Function characteristics	32%	
M-V-7	Instructional	Day 8: Function types	13%	
M-V-8	Instructional	Day 9: Function parts	60%	
M-V-9	Instructional	Day 10: Piecewise functions	22%	
M-V-10	Instructional	Day 11: Transformations	11%	
M-V-11	Instructional	Day 12: Quadratic functions	90%	
M-V-12	Instructional	Day 13: Word problems	72%	
O-A-2	Day 14	Test 2, Chapters 3-4		100%
	Day 15-19	Inverses/Word Problem Unit (Chapter 5)		
M-V-13	Instructional	Day 15: Inverse functions	9%	
M-V-14	Instructional	Day 16: Exponential functions	91%	
M-V-15	Instructional	Day 17: Logarithm functions	28%	
M-V-16	Instructional.	Day 18: Application word problems	88%	
M-V-17	Instructional	Day 19: Application word problems	89%	
O-A-3	Day 20	Test 3, Chapter 5		100%
	Day 21-26	Matrices/Conics/Sequences Unit (Chapters 6-8)		
M-V-18	Instructional	Day 21: Matrix introduction	53%	
M-V-19	Instructional	Day 22: Matrix concepts	68%	
M-V-20	Instructional	Day 23: Circles	0%	
M-V-21	Instructional	Day 24: Conic sections	14%	
M-V-22	Instructional	Day 25: Special patterns	9%	
M-V-23	Instructional	Day 26: Sequences & series	28%	
O-A-4	Day 27	Test 4, Chapters 6-8		100%
O-L-24	Day 28	Review-All Topics	50%	
O-A-5	Day 29	Final Exam, Comprehensive		100%

In Chapter 6, the tool provided a technological approach for working with matrices and problem solving complex systems of linear equations. In chapter 7, the instrument was used to connect the concept of circles to piecewise functions. In chapter 8, it was used for recursions and formula computations for sequences and series. The use of the calculator for these topics facilitated high order thinking by providing quick and fast access to the mathematical ideas not easily accessed using traditional methods. Otherwise, time would have been spent on learning the methods required to access the representations instead of time being spent to understand the representations between and among them to comprehend the concepts being studied.

Calculator Use and Multiple Representations

Instruction and class discussions were provided to develop students' conceptual understandings underlying the mathematics involved in the use of the graphing calculator, to explicitly help students understand the connections between the different representations and solution methods to promote mathematical fluency, and to integrate instruction of certain topics using model-based problems. The calculator was also used for isolated skill development along with algebraic, numerical, and graphical approaches.

Students asked questions about the use of the tool during instruction as well as questions about the representations created. Students used their preferred solution strategies when solving problems but were expected to learn and practice the graphing calculator procedures that were taught. In addition to the direct instruction and guided and independent practice for graphing calculator procedures received during class activities, students were expected to practice calculator procedures as they completed their homework assignments.

Calculator Use and Cognitive Levels

Analysis of the comparison of the percentages of time means for the received and acted on complex cognitive levels of information per units revealed that both levels increased gradually as the functional topics became more advanced from Unit 1 to Unit 3 as displayed in Figure 2. Moreover, the graphing calculator was used the greatest percentages of time for the functional topics in the three units. Likewise, when the percentages of time means for the received and acted on cognitive levels decreased during Unit 4, so did the percentages of time means of graphing calculator use. This topic will be discussed in greater detail in Chapter V.

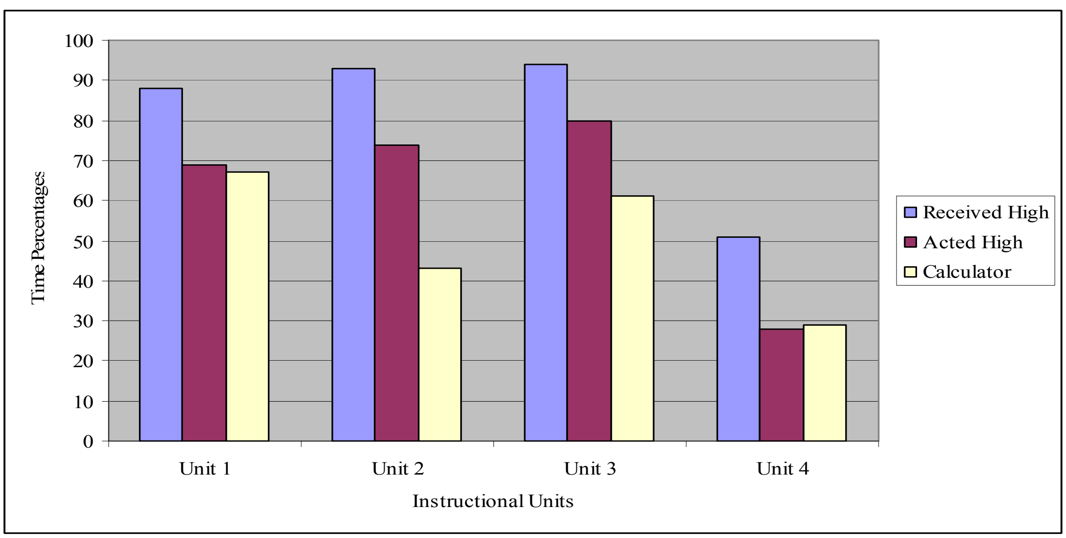


Figure 2. Comparison of the mean percentages of time students received and acted on high levels of cognitive information and used graphing calculators during instructional activities.

Calculator Use and Scaffolding Strategies

Analysis of the instructional scaffolding strategies used throughout the semester indicated more of an interactive group approach to teaching rather than the traditional use of lectures and demonstrations. Time spent using interactive group scaffolding approaches increased during the three functional units as the teacher-led scaffolding strategies decreased for those units. The calculator was used 87% of the time during the functional units indicating a positive relationship between the use of the tool and interactive group scaffolding strategies. Teacher-led and group scaffolding strategies were both used approximately 50% of the time during Unit 4.

Scaffolding Strategies and Homework

Scaffolding strategies described in the M-SCOPS for student work with minimal teacher supervision was rarely observed during class. However, homework assignments were designed to support students' independent work. Outside of class, high levels of student initiative and performance were required to fulfill the teacher's expectations for completing homework assignments and the practice tests especially since the work was not collected for a grade. Some assignments required students to review graphing calculator procedures and others required students to select their own solution approaches for completing the problems. Moreover, the answers to the assignments were given to the students so they could check their own answers and they were expected to ask questions about the problems they didn't understand at the beginning of class sessions. Students' initiatives were also high when making decisions to complete extra credit assignments.

Scaffolding Levels and Graphing Calculator Use

Means of the scaffolding levels determined by the M-SCOPS scripting, coding, and visual profiles protocols were used to determine the percentages of time the different levels were used during the semester: direct instruction at level 5-1 used 24%, teacher-led discussions at level 4-2 used 8%, group work at level 3-3 used 61%, small groups at level 2-4 used 6%, and open-ended work at level 1-5 used 1%.

To facilitate analysis of the different levels in relationship to graphing calculator use, the following levels were grouped together and categorized as follows: levels 5-1 and 4-2 were combined as teacher-led activities, and levels 3-3, 2-4, and 1-5 were combined as group or interactive student activities. Using the categories previously described for the scaffolding levels, the percentages of time for teacher-led activities was 32% and group activities was 68%. The means of the percentages of times that the different scaffolding levels were used was compared with the mean percentages of times the graphing calculator was used during instructional activities. A comparison of the means is displayed in Figure 3.

The analysis of the comparisons of the means suggested a positive relationship between graphing calculator use and the scaffolding strategies used during the interactive student activities. Although the graphing calculator was used the greatest amount of time during Unit 1, instruction related to calculator procedures and its use was

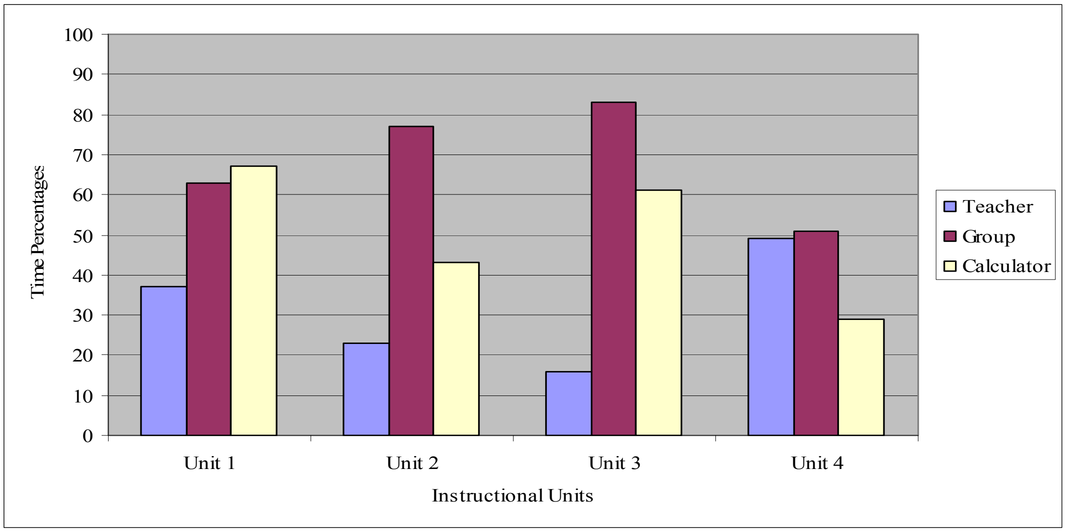


Figure 3. Comparison of the mean percentages of time different scaffolding levels and graphing calculators were used during instruction.

also the most intense during that unit, thereby saving time when the calculator was used for functional concepts in Unit 2 and Unit 3. Of the three units focusing on functions, the graphing calculator was used the least in Unit 2.

However, two particular topics in Unit 2, families of functions and transformation of functions, were concepts that the use of the graphing calculator could mask. Students were given specialty designed homework assignments designed to facilitate their exploration of those topics and to help them initiate conjectures about function characteristics and transformations. In class, instructional scaffolding strategies were used to support students' formulizations of generalizations for those concepts without the use of the graphing calculator. Students were not permitted to use the graphing calculator on the two quizzes that were used to assess students' understanding of characteristics of families of functions and transformations of functions.

Lesson Profiles

Differences in levels of instructional scaffolding and graphing calculator use can be seen in representative lessons from 4 the classroom profiles generated by the M-SCOPS observational tool. The four lessons were selected as examples of how strategic use of the graphing calculator can facilitate the delivery of instruction at high cognitive levels, support class interactions, and scaffold students' use of representations. The lessons represent different instructional strategies with graphing calculator use.

To facilitate descriptions of the 6 different cognitive levels used in the M-SCOPS coding scheme, the category levels were combined into two groups representing low and high cognitive levels. The low levels consisted of the cognition related to the categories of attend, replicate, and rearrange. The high levels consisted of the cognition related to the categories of transform, connect, and generate. For additional information pertaining to descriptions and examples of the coding used in creating the profiles see Appendix A.

Visual Profile: Class 1

The profile of Class 1 (see Appendix E) has been provided as a representative view of sustained group work under the teacher's guidance for a graphing calculator intensive modeling activity. The class followed the directions given in the self-directing and self-checking hand-out. The lesson has been divided into three segments according to students' focus (1) represents the teacher's opening remarks, (2) represents the group activity, (3) represents the teacher's closing comments.

The equal amounts of red of each side of the center vertical line suggests a shared responsibility between the teacher and the students in accomplishing the objectives related to the task. The other three colored bars represent the complexity level of cognitive information required to perform the simultaneous interactions occurring among different representations of symbols, pictures, and objects. Although doing the activity as directed on the hand-out would have been coded as replication, a low cognitive level, the discussions that occurred throughout the activity sustained a focus on understanding the transformations being made between the different representations raising the complexity of thinking required to a higher level.

Visual Profile: Class 2

The profile for Class 2 (see Appendix E) has been provided as a representative view of the different scaffolding levels that can be used during instruction and how the different methods for solving linear equations were validated. The shape of this profile differs dramatically from the profile for Class 1 with 8 segments displayed by different colors, lengths, and widths of the horizontal bars representing a more segmented lesson. Segment 1 and segment 8 represent the teacher's opening and closing comments respectively. The absence of the colors blue and green on segments 1, 3, 6, and 8 indicates that graphing calculators and graphs were not used during those times.

The varying levels of red represent the different scaffolding levels that were used during instruction. Instructional scaffolding provided in the first 4 segments led to the highest level of student initiated performance with small groups working and discussing the various ways to solve the different equations they were given. Students in each group were instructed to work the problem independently using their preferred approach, discuss their approach with their group, ensure that all the solution methods previously taught were represented, and check that all students understood how to perform the different methods.

The yellow section of Segment 6 represents the highest level of cognitive required during the lesson with the teacher facilitating students' discussions and evaluations of the other groups' different solution approaches to the problems completed in Segment 5. The internal processes used and the external representations created during the activity in Segment 5 became objects reflected upon, talked about, and evaluated during high level cognitive discussions.

Segment 7 shows a continuation of the lesson using scaffolding strategies during group work to help students transfer skills learned in previous segments for their use in solving quadratic equations. The scaffolding used in this lesson shows how the complexity of students' thinking and expressions can be raised to higher levels with the use of multiple forms of representations and skillfully orchestrated discussions.

Visual Profile: Class 3

The profile for Class 3 (see Appendix E) has been provided to show how graphing calculator use during meaningful discussions can be used to scaffold students understanding to higher cognitive levels. The five segments begin with the teacher answering students' questions about homework problems and ends with a summary of the lesson and connections between what was done in class and what the students could expect to see in their homework assignment. Direct instruction was used in Segment 2 to activate students' prior knowledge and to scaffold students' understanding of linear functions to higher levels by building on their present understandings.

The group activity in Segment 3 was a teacher-created modeling lesson, the car wash problem, designed to scaffold students' understanding of different linear function representations by collecting real-life data, displaying data in a table, graphing the data, and formulating an equation that represented the situation, the table, and the graph. Understanding how to make transformations from one representation to another was the focus of this segment.

Segment 4 represented a seamless transition scaffolding students' understanding to the next cognitive level through discussions about the representations facilitated by the interactive and dynamic features of the graphing calculator that was used to verify the equation, the table, and the graph that was completed by hand. Time was saved in this segment because students' already had their calculators on their tables ready to be used and they had already been taught the calculator procedures necessary to perform the task. The instructional scaffolding used for Segment 4 was enabled by the skillful orchestration of the activity and the sequencing of instructional lessons that permitted sustained focus on understanding the connections among the representational forms used in the car wash activity.

Visual Profile: Class 16

The profile for Class 16 (see Appendix E) has been provided because the highest scaffolding level of student performance and initiative was used in this lesson. Segment 1 opened with an exploratory task being assigned to students regarding representations of a function not previously studied in the course. Mrs. A had entered the class, wrote an exponential equation on the board, constructed a table of values with specific domain values on the board, and then handed each student a sheet of graph paper. She said, "I want to see what you can do. Use the equation to help you complete the table and construct a graph that represents it." Then she left the room without further comments.

In Segment 2 students discussed how they could complete the task. Mrs. A returned to the class and asked each student how they had completed the task. All the students had used the calculator to complete the table being able to transfer their prior knowledge about functions and calculator use to a function they did not have experience with in this course. During the group work in Segment 4, the table was completed by hand and the characteristics of exponential functions were discussed using the representations created by the students in Segment 2.

Additional group work was conducted in Segment 5 and Segment 6 leading to a higher scaffolding level used in Segment 6 where students were given time to work on certain problems and the teacher was available to answer any clarifying questions or to offer assistance if needed. In Segment 8, students described their different approaches to a given problem and were given a chance to modify their reasoning when the other students evaluated their approach.

Section III: Students' Responses to Graphing Calculator Use

Analyzed data was triangulated to derive the third finding: all students used the calculator during instructional and assessment activities self-reporting that their use of the calculator was generally beneficial for enhancing their understanding of lessons, supporting class interactions, and improving test performance. Constant comparative and content analysis methods were used to analyze students' self-reported data received from lesson questionnaires completed after each of the 23 instructional lessons and the assessment questionnaires after the 4 unit tests and the final exam.

Means of students' responses to the statements that the use of the graphing calculator was beneficial for enhancing their understanding of the lessons was 94% and that the tools use facilitated class interactions that enhanced their understanding of the lessons was 92%. Student data indicated that the projection of the instructor's calculator's screen image supported their use of the graphing calculator during class 99% of the time. On major assessments, all students chose to use the tool responding favorably to statements regarding use of the tool for major assessments with few exceptions.

Each student received a questionnaire to complete immediately after each class session. Their responses on the questionnaires were considered a reflection of their perspective of how the graphing calculator was used during that class. Two different questionnaires were used depending on the focus of the class session. Lesson questionnaires were completed after lessons and assessment questionnaires were completed after major assessments. When students were finished filling out the questionnaire, they either gave them to me or left them on the table for me to pick up.

Calculator Use and Enhanced Understanding

Data from the lesson questionnaires provided information about students' perceptions about graphing calculator use for that particular class. Students were to respond to how beneficial they felt the graphing calculator was in enhancing their understanding of the lesson. The statistical analysis measure of mean was used to determine the following results of how beneficial the students felt the graphing calculator was in enhancing their understanding of the lesson: very beneficial of 60%, moderately beneficial of 34%, and not beneficial of 6%. Figure 4 provides a visual

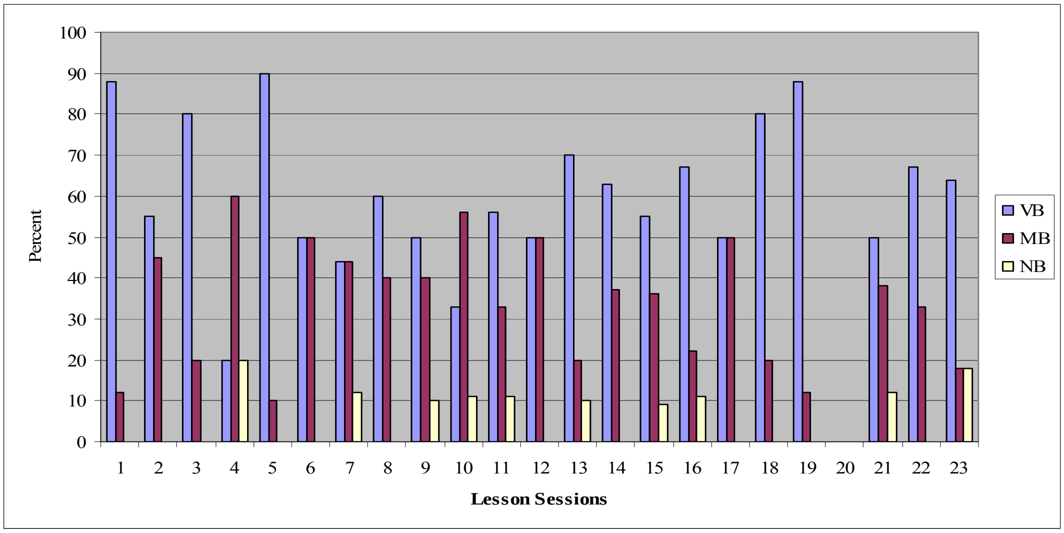


Figure 4: Percentages of students' responses on how beneficial the use of the graphing calculator was for enhancing their understanding of each lesson.

Note. VB-very beneficial, MB-moderately beneficial, and NB-not beneficial.

display of students' responses during all of the lessons. Of the negative open-ended free responses received for the lesson, content analysis determined that 62% of the responses indicated that the use of the tool was minimal and not essential for understanding the lesson. Student 7 response was 7% of the negative responses and was a complaint about not being able to use the calculator on the function transformation quiz. Three students (Students 2, 4, and 5) of the nontraditional college age category who had never used a graphing calculator before this course, indicated confusion about the tool's use four times for 31% of the negative responses.

Calculator Use and Discussion Support

The graphing calculator was used during instructional scaffolding strategies during collaborative activities. Figure 5 provides a visual display of the means of

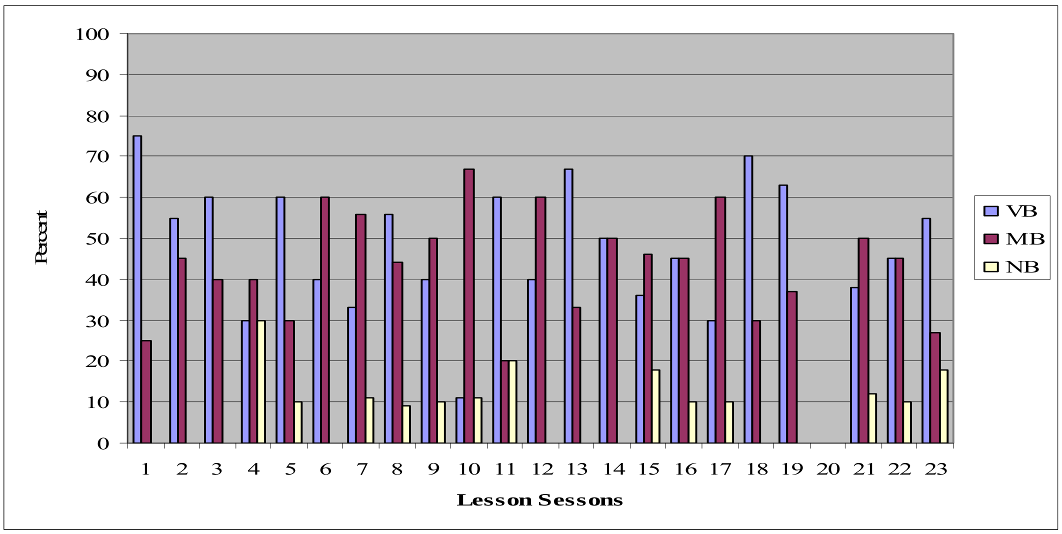


Figure 5: Percentages of students' responses on how beneficial the use of the graphing calculator was in supporting discussion that enhanced their understanding of each lesson.

Note. VB-very beneficial, MB-moderately beneficial, and NB-not beneficial.

students' responses for the 23 lessons. Students responded to how beneficial the calculator was in enhancing their understanding of the lesson through the stimulation and support of class interactions. The statistical analysis measure of mean was used to determine the following results: very beneficial of 48%, moderately beneficial of 44%, and not beneficial of 8%. The majority of the not beneficial responses were from two students, Student 4 with 41% and Student 5 with 29%. Both of these students did not have prior experience with graphing calculators.

Calculator Use and Screen Projections

Figure 6 shows the mean percentages of students' self-reported data indicating the beneficial use of the graphing calculator view screen projection in helping them

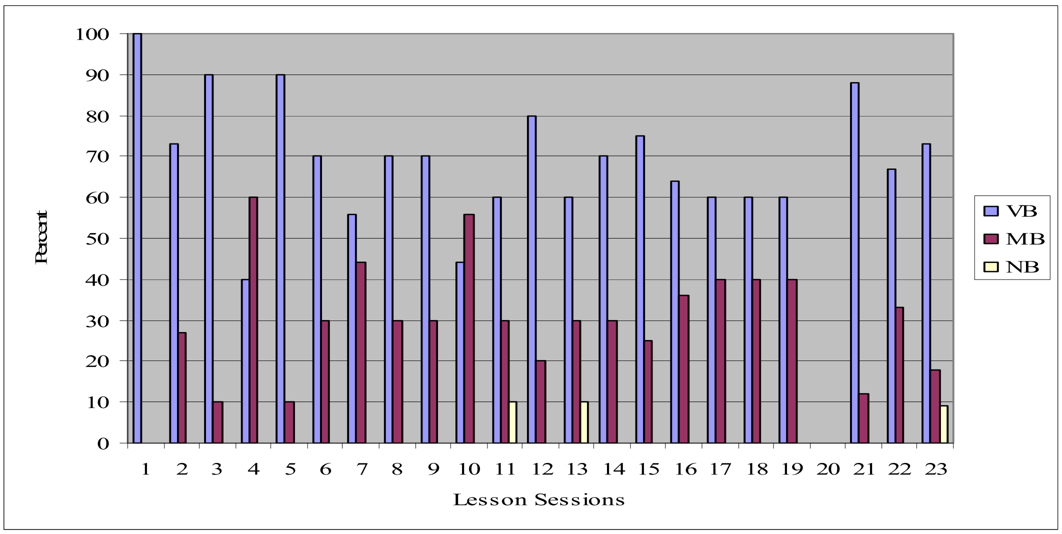


Figure 6: Percentages of students' responses to the beneficial support provided by the use of the external graphing calculator projection during each lesson.

Note. VB-very beneficial, MB-moderately beneficial, and NB-not beneficial.

follow along with the teacher's use of the tool during class. The statistical analysis measure of mean was used to determine the following results: very beneficial of 67%, moderately beneficial of 32%, and not beneficial of 1%. The calculator was not used during lesson 20 on the topic of circles as a conic section.

Calculator Use and Test Problems

Students had a choice of whether or not to use the graphing calculator for major tests. All students who completed an assessment questionnaire during the regular class session self-reported using the graphing calculator for the test that was supported by the researcher's observations. Students' responded to questionnaire items 2-13 that provided information on how the students felt about using the calculator for that assessment.

Although all students used the graphing calculator to some extent on the test, the number of problems they used with the calculator varied among students. Figure 7

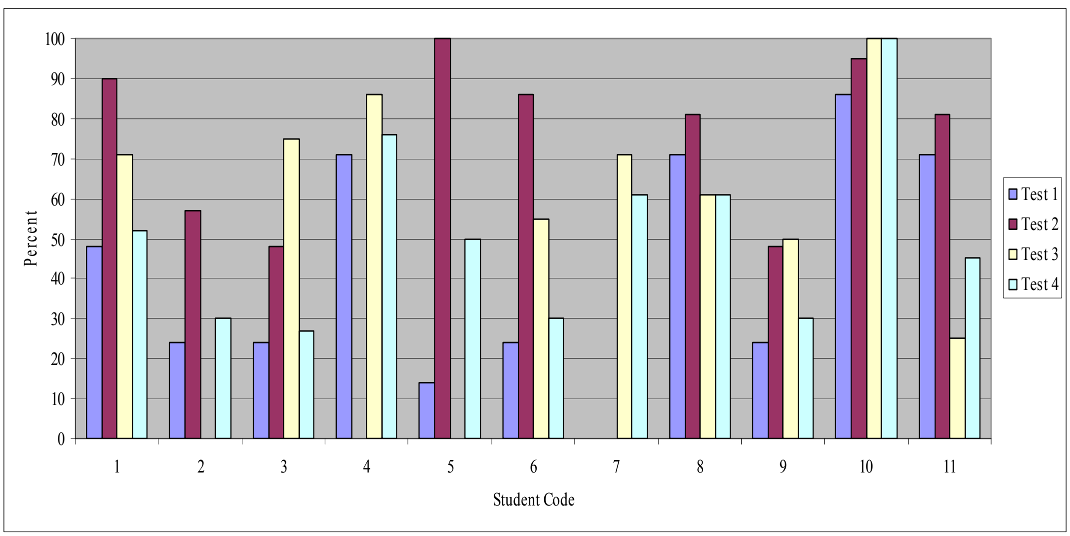


Figure 7: Percentage of problems students used the graphing calculator on tests.

shows the students' responses to questionnaire item 2 in which they were asked to record the number of problems for they used the graphing calculator. Based on the information given in the assessment questionnaires, students used the graphing calculator for fewer problems on Test 1 then the other tests with the exception of Students 8 and 11. This figure will be discussed in more detail in Chapter V.

Calculator Use and Today's Test

Students were provided the opportunity to complete the prompt, *using the graphing calculator for today's test*, on item three of the student assessment questionnaire. Students' responses were analyzed using the constant comparative method. The percent of positive and negative student responses were 94% and 6% respectively. The word "helped" was used in 77% of the students' responses to the item. Students' responses were analyzed and a synthesized list has been displayed in Table 14 listing from the highest to the lowest percent of response.

Table 14
Synthesis of Students' Responses to the Prompt: Using the Graphing Calculator for Today's Test

Number	Synthesis of Responses	Percent of Responses
1	Helped	28%
2	Helped solve problems	23&
3	Finish problems faster	17%
4	Made test easier	15%
5	Get a better grade	9%
6	Helped with understanding	6%
7	Check work	6%

All students' responses for this item were positive in nature except for Student 11's comment on Test 3, "was tricky, I couldn't remember anything." Student 5, who did not have calculator experience before this course, writes that the calculator was used as a tool for checking or rethinking problems for Test 1 and that it provided a visual for abstract ideas for Test 2. Student 6 had used the calculator before this course and relates that the calculator helped with understanding on Tests 3 and 5.

Calculator Use and Confidence

Questionnaire items 4-10 were Likert statement items that elicited students' responses to statements about graphing calculator use during the assessments. With few exceptions, students responded favorably to the statements regarding graphing calculator use. Figure 8 contains students' Likert score responses to the statement: I was confident in using the calculator during today's test. Of the responses given, 88% were at the

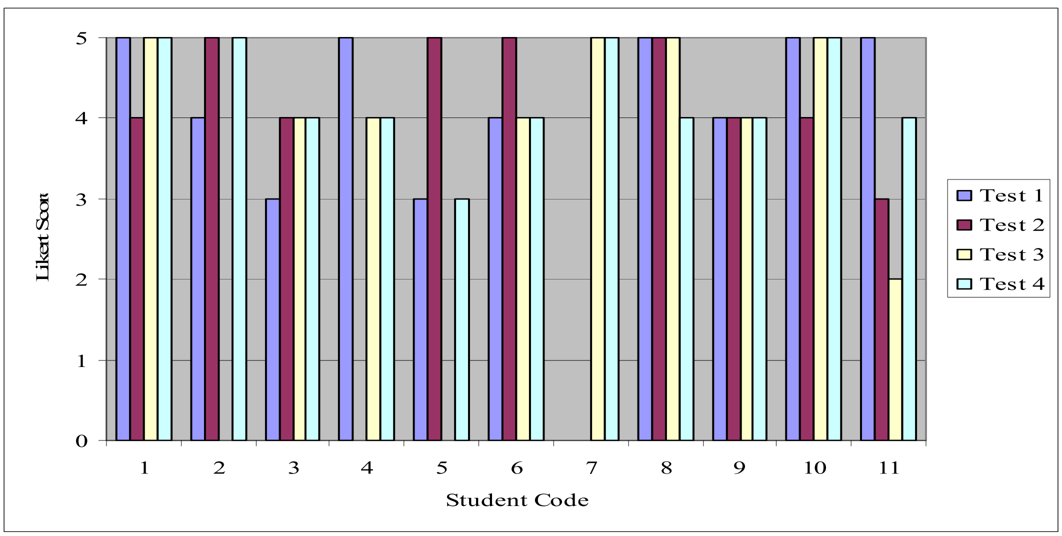


Figure 8: Students' Likert scores for the statement: I was confident in using the calculator during today's test.

positive range of the Likert scale with 44% strongly agreed, 44% agree, 10% undecided, and 2% disagree. Student 3 recorded undecided for Test 1 but confidence in using the calculator increased to agree for Tests 2-4. Student 5 was undecided about confidence in using the tool for Test 1 and 4 but recorded strongly agree for confidence in using it for Test 2. The most difference in student responses for this item occurred with Student 11 who had no experience with a graphing calculator before this course. A strongly agree was recorded for Test 1, an undecided for Test 2, disagree for Test 3, and agree for Test 4. The response for Test 3, disagree, corresponds to the written response on item 3 that using the calculator on today's quiz/test "was tricky couldn't remember anything."

Calculator Use and Procedures

Questionnaire Likert item 5: I was not sure about how to use the calculator during the test, required students to reflect about their assurance knowing how to use the tool during the assessment. Students' responses are recorded in Figure 9. Of the responses given 84% were in the negative range of the Likert scale with 35% strongly disagree, 49% disagree, 14% undecided, and 2% agree. Student 5 was undecided for Tests 1 and 4 but strongly disagreed with the statement on Test 3. Student 6 disagreed with the statement on Tests 1, 2, and 4 but was undecided on Test 3. Student 11, who had no previous graphing calculator experience before this course, recorded the widest range of responses this statement recording a strongly disagree on Test 1, disagree on Test 2 and 4, and agree on Test 3. Student 11 was the only student with a positive response to this statement but the response was consistent with other responses on the Test 3 assessment questionnaire.

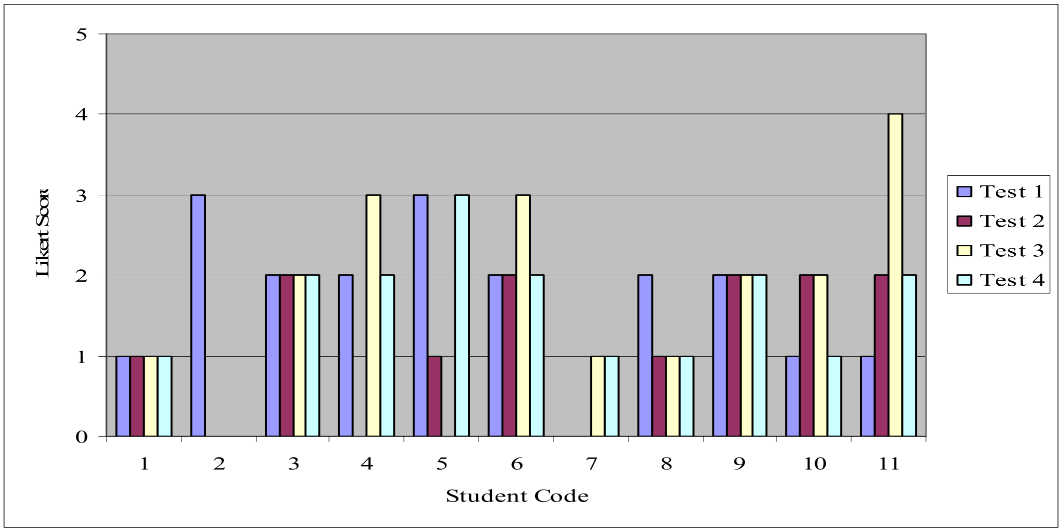


Figure 9: Students' Likert scores for the statement: I was not sure about how to use the calculator during the test.

Calculator Use and Key Punching

Questionnaire Likert item 6: I feel like I just punched keys without understanding why, required students to reflect upon whether or not they understood why they were doing certain key strokes. Students' Likert values given this statement are displayed in Figure 10. Of the responses given, 92% were in the negative range of the Likert scale with 48% of strongly disagree and 43% disagree. Recording undecided responses to the statement were students who had no experience with graphing calculators before this course, Student 5 for Tests 1 and 4 and Student 11 for Test 2.

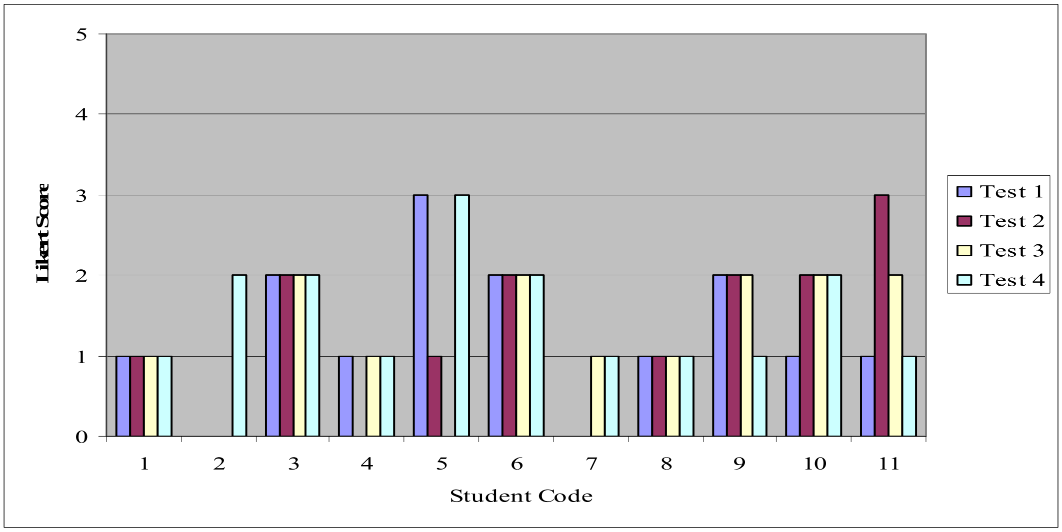


Figure 10: Students' Likert scores for the statement: I feel like I just punched keys without understanding why.

Calculator Use and Test Ease

Figure 11 presents a visual display of students' Likert score responses to questionnaire item 7 that required students to reflect on whether or not they felt the use of the graphing calculator made the test easier than if they just used paper and pencils. Of the responses given, 90% were toward the positive range of the Likert scale with 72% strongly agreed and 18% agree. Undecided responses were given by Student 3 on Test 1, Student 5 on Test 4, and Student 9 on Test 1. The only negative response to this statement was given by Student 3 who also had the widest range of responses for this item with undecided for Test 1, strongly agree for Test 2, strongly disagree for Test 3, and strongly agree for Test 4. Student 4 had not used the graphing calculator before this course.

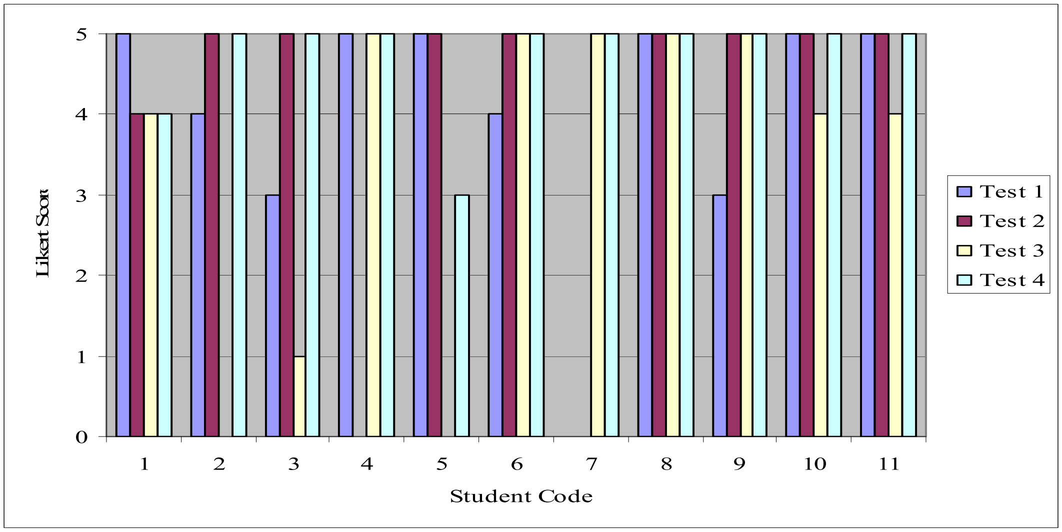


Figure 11: Students' Likert scores for the statement: I think using the calculator made the test easier to complete then using just paper and pencil.

Calculator Use and Method Approach

For questionnaire Likert statement item 8, students were to respond to whether or not they first worked problems using paper and pencil and then used the graphing calculator to check their answers. Figure 12 provides a visual display of students' responses to this item. Student's responses to item 8 indicate their preference for how they chose to complete the test. Ten students favored doing the work by hand with 5 strongly agrees and 5 agree responses. Five students were undecided about their preference. Twenty-four students favored the negative range of the Likert-scale for this item with 17 disagrees and 7 strongly disagree. Students' negative responses to this item indicate their reference for using only the calculator for certain assessment items.

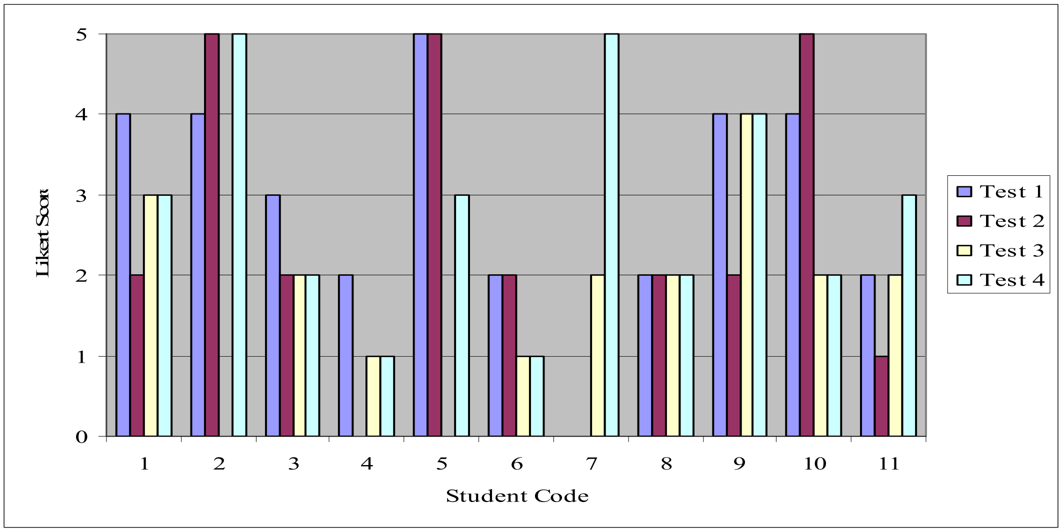


Figure 12: Students' Likert scores for the statement: I worked the problems using paper and pencil and then used the calculator to check my answers.

Three students who had experiences with graphing calculators before this course indicated a preference for doing problems with paper and pencil before using the calculator: Student 7 on Test 4, Student 9 on Tests 1, 3, and 4, and Student 10 on Test 2 only.

Calculator Use and Time Saved

Likert item 9 required students to reflect on whether or not they felt that using the calculator saved time as opposed to just using paper and pencils for the test. Visual displays of students' responses are presented in Figure 13. Responses in the positive range of the Likert value was at 82%. The two students who disagreed with the statement, Student 3 on Test 1 and Student 10 on Test 2, responded favorably on subsequent assessments. Student 10 was the only student who had prior experiences with the graphing calculator who responded negatively to this item with disagree recorded for

Test 2. Student 5 was undecided about the time issue for this item for Test 1 and Test 4. Student 11 was undecided about this item for Tests 2-4.

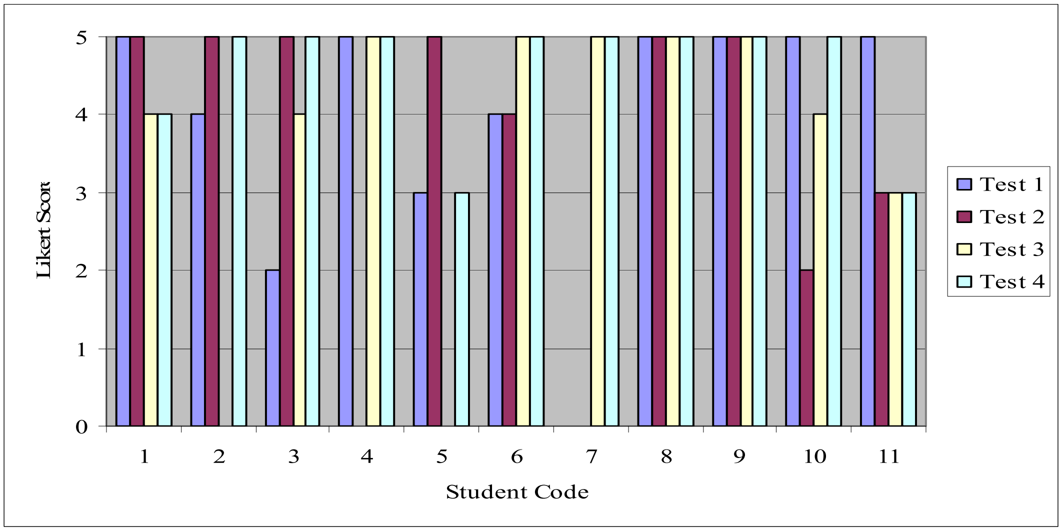


Figure 13: Students' Likert scores for the statement: Using the calculator saved time compared to just using paper and pencil to complete the test.

Calculator Use and Better Grades

Likert item 10 required students to reflect upon whether or not they felt that being able to use the graphing calculator for the test would result in a better grade than if they would have just had paper and pencil to use. Figure 14 provides a visual display of students' responses to this item on the four major unit tests. The majority of students self-reported that being able to use the graphing calculator would result in a better grade than they would have had with just using paper and pencils with a total of 69% strongly agree and 21% agree for a total of 90% positive responses. Student 3 was the only

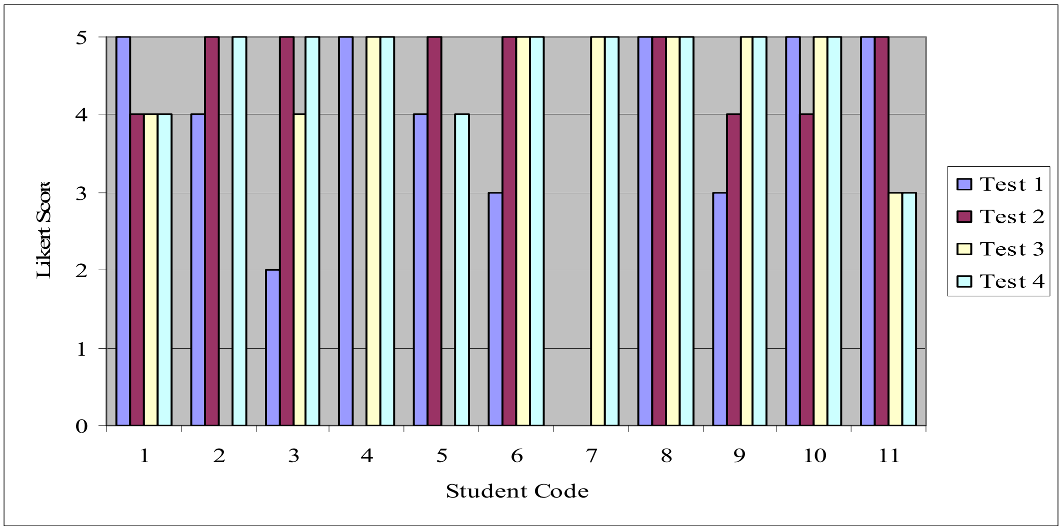


Figure 14: Students' Likert scores for the statement: I feel that being able to use the graphing calculator for today's test will result in a better grade than I would have had with just paper and pencil.

student to disagree with the statement on Test 1 but changed to positive responses with a strongly agree on Tests 2 and 4 and agree on Test 3. Student 9 responses to this statement changed from an undecided on Test 1 to agree on Test 2 to strongly agree for Tests 3 and 4. Both Student 3 and 9 increased to more positive responses for subsequent tests. Student 11 was the only student who responded strongly agreed to Test 1 and 2 and then had responded less favorable with an undecided for Tests 3 and 4. This response from Student 11 is consistent with other responses on the student's questionnaire for Test 3 and 4.

Calculator Use and Test Advantages

The last three items on the questionnaire were open-form prompts to provide students the opportunity to add comments about advantages or disadvantages about graphing calculator use for the assessment or anything else they wanted to add. Table 15 contains the six responses to the advantages for using the calculator for the assessment.

Table 15

Students' Responses to the Questionnaire Open Form Item 11: Please record any additional advantages for using the graphing calculator for this assessment

Student 1
Test 2: It would have been very difficult to even try many of the problems without the graphing calculator.
Student 2
Test 1: It helped for finding and checking answers.
Test 2: Helped me find answers I couldn't on my own.
Student 4
Test 1: Able to get answers without knowing all the algebra steps
Student 5
Test 1: Check, recheck, analyze, and rethink work
Test 2: Gives a visual instead of abstract idea!

Three comments related to Test 1. Two responses indicated the calculator was used to check their work and the other comment referred to getting answers without using traditional methods. Three comments related to Test 2. Two responses indicated that the calculator was needed to determine solutions some of the problems and one response refer to the visual aspects the calculator offers.

Calculator Use and Test Disadvantages

Open form item 12 gave students an opportunity to offer their reflections about disadvantages for using the graphing calculator for the assessments. The responses of the two students who responded to this item are contained in Table 16. Disadvantages given by students for using the graphing calculator were given by Student 5 and 9. Student 5 writes about fearing dependency on the calculator for Test 1 and for Test 4 was still concerned about depending on the calculator's key strokes. Student 9 forgot about how to use the calculator for some problems on Test 1.

Table 16
Students' Responses to the Questionnaire Open Form Item 12: Please record any additional disadvantages for using the graphing calculator for this assessment

Student 5: Test 1: Fear of dependency Test 4: Allows you to depend on key strokes.
Student 9 Test 1: I forgot how to use it on a few problems.

Calculator Use and Test Reflections

The last item on student assessment questionnaire provided students an opportunity to offer any additional comments or reflections. The responses of the three students who responded to this item are contained in Table 17.

Table 17
Students' Responses to the Questionnaire Open Form Item 13: Please record any additional comments or reflections

Student 1 Test 2: I am feeling much more confident in using the calculator and know much more about which buttons to push in a given situation. It's definitely helped to ease some of my test anxiety.
Student 5 Test 1: Need to work at calculator more
Student 6 Test 1: I feel that the graphing calculator is extremely helpful!

All three students had never used the graphing calculator before this course. The reflections of two of the students were positive toward calculator use indicating that it was helpful and lessened test anxiety. The other student recognized the need for more practice using the calculator.

Calculator Use and Individual Students

Although six of the eleven students had never used a graphing calculator before this course, the students appropriately used the calculator during instructional activities and independently chose to use the tool during tests. Their responses on the assessment questionnaires indicate that the graphing calculator was used with confidence and understanding and that use of the graphing calculator made the test seem easier and faster to complete compared to doing the test with just paper and pencil. The students indicated they felt the use of the graphing calculator would result in a better grade than they would have had without the tool 90% of the time during major assessments.

Student 1

Student 1 had never used a graphing calculator before and had struggled with confusion about algebra and math anxiety before the course. Comments made on the lesson questionnaires indicated that she now realizes how helpful a calculator can be to help understand the material, to verify work, to visualize problems, to prepare for tests, to succeed on tests, and to ease test anxiety.

Student 2

Student 2 who had never used a graphing calculator before this course reported that the tool helped her to understand the class work, to complete homework assignments, and to prepare for tests. She reported being somewhat confused on 8% of the lessons with graphing calculator use.

Student 3

Student 3 who had never used a graphing calculator before the semester commented about being overwhelmed with its use in lesson 2 but added in the next lesson that she starting to understand it more.

Student 4

Student 4 who had never used a graphing calculator before reported that its use was helpful and relieved a lot of mathematical stress.

Student 5

Student 5 who had never used a graphing calculator before reported that its use during lessons was confusing for 25% of lessons at the rate of the information given but that she was slowly learning math with the tool. On the other hand, she reported that the instrument "remains the constant-allows me to understand" and it helped her feel the possibility of success for the course.

Student 6

Student 6 considered graphing calculators a complete puzzle before the course even though she had opportunities to use one in another math class. Although reporting she needed more calculator practice early in the course, she later reported that it helped her understand the lessons better and made the problems easier understand and work.

Student 7

Student 7 reported loving to use the calculator and that it was used daily her high school mathematics class. She recorded that the calculator did not help in one class because she couldn't use it on the transformation quiz.

Student 8

Student 8 was concerned about not being able to handle the class material at the beginning of the course. She reported that using the graphing calculator helped make the lessons easier to understand.

Student 9

Student 9 had used the graphing calculator in her high school math classes and reported that the tools' use was helpful for solving problems and doing homework. In unit 3 she reported getting confused about the different keystrokes to use and being overloaded with information.

Student 11

Student 11 had never used a graphing calculator before and recorded that learning to use the tool was interesting and that it was especially helpful for word problems. He was the only student who personified the calculator reporting that it seemed to be "temperamental" at times.

Student 10

Student 10 has been described in more detail than the other students because he was the only individual that completed all four unit tests and the final exam. He was the only student that was required to take the final exam because the other students were exempt having received an average of B or better in the course so far. A male of traditional college age, his responses to the initial background questionnaire indicated a lack of knowledgeable graphing calculator use although he had used a graphing calculator in three high school mathematics classes.

His responses to statements on the lesson questionnaires indicate that the use of the graphing calculator enhanced his understanding of the lessons as very beneficial 2% of the time and moderately beneficial 98% of the time. His responses to the tool for stimulating and supporting interactions that enhanced his understanding of the lesson were recorded moderately beneficial 100% of the time. His responses to the use of the instructor's projected calculator image were 20% very beneficial and 80% moderately beneficial.

The student completed assessment questionnaires regarding graphing calculator use immediately following the four unit tests and the final exam. Responses to the statements provided insight to how graphing calculator use was perceived by the student for the assessments. Comparisons of the students' responses to the statements among the assessments provided information regarding changes in student's perceptions about the tool and are displayed in Figure 15.

Likert statement items 4-7 focused on to confidence, knowledge, and understanding concerning graphing calculator use. Likert statement item 4, I was confident in using the calculator during today's test, received strongly agree for Test 1, agree for Test 2 and Test 3, and then back to strongly agree responses for Test 4 and the exam, indicating an increased confidence in the tool's use for the last two assessments. Moreover, the student's response of undecided to a similar Likert statement on the initial background questionnaire (Q-I-1), I am confident in my ability to use a graphing calculator, indicated an increased level of confidence in the student's ability to use the graphing calculator during the course of the semester.

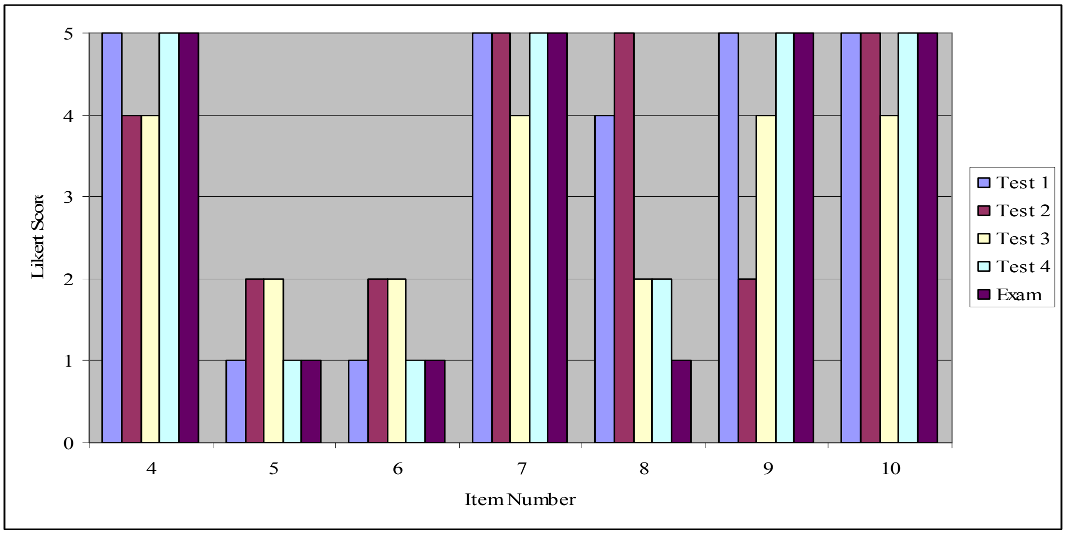


Figure 15: Student 10's Likert scores on the assessment questionnaires for 4 unit tests and the final exam.

Likert item 5, I was not sure about how to use the calculator during the test, and item 6, I feel like I just punched keys without understanding why, the negative responses changed from strongly disagrees for Test 1, to disagrees for Test 2 and Test 3, then back to strongly disagrees for Test 4 and the exam indicating an increased knowledge and understanding of how to use the tool. With the exception of the data from Test 1, the data from responses to statement items 4-6 indicates positive increases in the student's confidence, knowledge, and understanding about graphing calculator use during the rest of the course.

Likert statement item 7 and item 9 focused on graphing calculator use for tests as opposed to just paper and pencil regarding making the test easier and saving time respectively. Responses to the statement about making the test easier were strongly agree for Test 1, Test 2, Test 4, and exam and agree for Test 3. However, responses about saving time were more varied among the assessments receiving strongly agree for Test 1, disagree for Test 2, agree for Test 3, and strongly agree for Test 4 and the exam. With the exception of Test 1, student responses for item 9 indicate progressive improvement in the student's proficiency in using the graphing calculator resulting in time being saved during testing.

Likert statement item 8 concerns students' use of traditional solution strategies, working problems by hand using paper and pencil, as opposed to reform methods, appropriate use of the graphing calculator. Student's responses to the statement, I worked the problems using paper and pencil and then used the calculator to check my answers, were more varied than any of the other Likert items ranging from agrees on Test 1, strongly agree on Test 2, disagree on Test 3 and Test 4, to strongly disagree on the final exam. This data was compared to the percent of problems for which the student used the graphing calculator, 86% for Test 1, 95% for Test 2, 100% for Test 3, 100% for Test 4, and 86% for the exam.

Additionally, on the initial background questionnaire (Q-I-1), the student responded undecided to the statement; I would refer not to use a graphing calculator in class. Interpretive analysis of the data indicated that the student had a progressive change of perspective regarding solution strategies moving from working problems by hand then using the calculator to check the work, to the use of graphing calculator methods without first working the problem by hand. The change of perspective represented a move from favoring traditional solution methods using paper and pencil to preferring reform strategies using a graphing calculator.

The last Likert statement was item 10, I feel that being able to use the graphing calculator for today's test will result in a better grade that I would have had with just paper and pencil. The student responded with a strongly agree on Test 1, Test 2, Test 4, and the exam and agree on Test 3 indicating positive responses regarding graphing calculator use for assessments as opposed to traditional methods using paper and pencil. For both item 7 and item 10 regarding the use of the graphing calculator for making the test easier and getting a better grade respectively, Test 3 was the only assessment for which the student did not record a strongly agree with both items receiving agreed and the student received his lowest test score on this assessment.

Student 10's self-reported responses indicated advancement in knowledgeable use of the graphing calculator, an increased preference for calculator solution approaches, improved confidence when using the tool, and continued belief that using the calculator would result in improved test performance.

Summary

This chapter provided the findings of the research study supported by data analyzed using the constant comparative method, content analysis, and statistical measures. The analyzed data were triangulated using multiple and/or different sources that included M-SCOPS, observation field notes, teacher and student questionnaires, and varied documents. The findings indicate that Mrs. A orchestrated specialized instruction, materials, and activities to integrate the graphing calculator into the classroom as a teaching and learning tool for certain college algebra concepts and skills.

Her proactive instructional practices served to initiate and to promote desired classroom norms according to her goals for the class that included graphing calculator use. In the classroom, the dynamic and interactive features of the graphing calculator facilitated access to, exploration of, and use of multiple representations for some mathematical concepts and solutions not easily attainable using traditional methods.

Students' use of the graphing calculator was supported by instruction, materials, and activities that provided the experiences that promoted students use of the instrument. With few exceptions, the students responded positively to graphing calculator use during instruction reporting that their understanding of the lesson was enhanced and that class interactions were supported by use of the tool. All students chose to use the graphing calculator on major assessments responding that they felt the use of the tool would improve their performance resulting in a better grade than they would have received without it. With few exceptions, students' responses to assessment questionnaire items indicated that the tool was used with understanding and confidence during the assessments. These findings will be discussed further in Chapter V.

CHAPTER V

CONCLUSIONS

This chapter will provide a summary of the study's findings, discussions about conclusions made, suggestions for instructional practices, and recommendations for further study. The chapter is divided into three sections. Section one presents a summary of the purpose, methods, and findings of the study. Conclusion related to the research questions in light of previous research are provided in section two. Section three provides recommendations on graphing calculator issues related to instructional practices, equity concerns, and future research.

Purpose, Methods, and Findings

The purpose of this case study was to contribute to research knowledge about the relationships among aspects of a college algebra class when graphing calculators were used to determine patterns in the use of the tool with the development of classroom norms and to evaluate how the tool was used by class members. To accomplish the research goals, an interpretative case study design approach was used to study one purposively selected individual's class. The lens from which the elements of this study were viewed drew from the perspective of the Multiple Representations Model of Learning and Teaching (Stuessy, 2005) and the perspective of the affective representational systems (Goldin, 2003). Investigation of the phenomenon was guided by the main research question: What happens when an exemplary teacher uses graphing calculators in a college algebra class? Questions supporting the main focus included the following:

1. What classroom behaviors and interactions become routine when graphing calculators are used and how does the tool promote those actions?
2. What instructional patterns and strategies occur when an exemplary teacher uses graphing calculators in a college algebra course?
3. How do students respond to the use of the graphing calculators?

Data collected during the study included classroom observations, field notes, teacher and student questionnaires, informal interviews, and documents. The M-SCOPS protocols and constant comparative and content analysis methods were used to analyze data. Triangulation of data analysis and sources were used to support the study's three findings:

1. The instructor's proactive orchestration of specialized instruction, support materials, and designed activities contributed to the establishment of graphing calculator use as an essential part of classroom norms and promoted students' independent use of the tool.
2. The dynamic and interactive features of the graphing calculator facilitated the delivery of instruction at high cognitive levels during student interactive activities by providing access to, exploration of, and use of multiple representations for some mathematical concepts and solutions not easily attainable using traditional approaches using paper and pencil methods.

3. Students self-reported that graphing calculator use was generally beneficial for enhancing their understanding of lessons, facilitating class interactions during lessons, and improving performance on tests.

The three findings of this study were intrinsically related and can be explained using the perspective of the Multiple Representations Model of Learning and Teaching (Stuessy, 2005). The model provided the framework for the study and facilitated explanations about the interactions described between the teacher, students, materials, and graphing calculators in the classroom.

Discussion of Results

The main purpose of the study was to describe what happens when an exemplary teacher uses graphing calculators in a college algebra class. The role of the graphing calculator on the development of classroom norms, use for instructional practices, and influence on students' perspectives were examined. Based on the study's findings in light of previous research that will be discussed, the following statements were formulated:

1. The instructor played a vital role in initiating, promoting, and supporting student behaviors during integrated instructional activities that led to the establishment of graphing calculator use and related interactions as classroom norms.
2. The instructor's rich utilization of the graphing calculator during innovative instructional activities promoted active student participation through interactions with their personal calculators and with other class members that generally enhanced students' understanding of the mathematical concepts being taught.

3. Students' independently chose to use the graphing calculator for varied reasons including enhanced understanding, solution strategies, saving time, making problems easier, visualization, improved test performance. For some students, being able to use the graphing calculator during lessons and assessments helped relieve some of the anxiety they felt when doing mathematics and testing.

Discussion: First Finding

The results of this study indicated that the instructor's rich utilization of graphing calculator technology during integrated instructional activities promoted negotiation of interactions and behaviors. These activities lead to the establishment of graphing calculator use and related interactions as an integral part of the classroom norms. Seamless incorporation of graphing calculator use for class activities was possible since all students had a personal TI-83 or TI-84 series graphing calculator whenever they needed to use the tool.

The classroom was set up to facilitate interactions among members through the use of tables that accommodated four students. The seating arrangement portrayed a sense of learning through collaboration instead of learning in isolation as often conveyed by individual desks in traditional classrooms. The majority of the classroom norms identified in this study were initiated during the first day of class during an activity using graphing calculators. The innovative use of the graphing calculator the first day of class showed how use of the tool can help set up situations that offer opportunities for expressions of student expectations as well as students' subsequent responses during instructional activities.

Community of Learners

The classroom norms established in this study were indications of characteristics of a community of learners that engaged in activities designed to promote understanding and communication of mathematics. The instructors' expectations of students' engagement and participation in the student interactive instructional activities reflected the belief that learning was an active process. This process was facilitated by collaboration with other individuals and interactions with materials and the graphing calculator supported by appropriate instructional scaffolding.

The findings of this study support the research of Goos (2004) that highlighted the teacher's vital role in establishing norms and practices that led to the creation of a classroom community. In Goos' (2004) two-year study of a secondary mathematics classroom, a spirit of inquiry was cultivated that emphasized mathematical sense-making and justification of ideas. The students' participation in a community of mathematical inquiry was facilitated by (1) scaffolding, (2) peer collaboration, and (3) interweaving of concepts. The three strategies were similar to Mrs. A's approach in promoting a community of learners that focused their attention on the understanding of mathematical concepts through representational forms using instructional scaffolding during interactive activities.

Innovative Practices

Being knowledgeable about current research and reform recommended instructional approaches to promote students' understanding and achievement in mathematics was important to Mrs. A as shown through her participation in professional development activities throughout her career. Her knowledge of content, pedagogy, resources, and students was used to create a safe affective classroom atmosphere in which students felt comfortable taking risks in asking questions, requesting help, and offering ideas. Her commitment to successful student course outcomes included attention to students' feeling, strategies to promote class interactions, instructional approaches to advance mathematical understandings, the use of multiple solution strategies, making connections between multiple representations and other areas, explicit instruction on graphing calculator use, provision of support materials and networks, and use of formative and summative assessments.

The innovative practices used by the teacher in this study are characteristic of reform practices and pedagogical approaches advocated by the AMATYC (2006) in efforts to promote equitable access to quality mathematics instruction for all students. Positive relationships between highly reformed teaching and enhanced student learning was supported by the research of Sawada et al. (2002) in their analysis of teaching practices that focused on lesson design and implementation, content, classroom culture, and student and teacher relationships. Their study supports the importance of the teacher fostering positive student relationships that serve to promote interactions leading to the development of classroom norms that facilitate teaching and learning behaviors.

In this present study, Mrs. A demonstrated her understanding of adult students by exhibiting respect, interest, and concern for the students from the very first day of class by making sure each individual felt comfortable using the graphing calculator for the activity, requesting information about their past math experiences, and asking how she could best help them learn mathematics. Concern for students' feelings reflects a belief that affective representations such as feelings and emotions are interrelated with the cognitive processes involved in learning (Goldin, 2003). Strategies taken to minimize student stress and anxiety during class activities and interactions included respect for all students' ideas and encouragements to ask class members for help when it is needed that eventually became part of the classroom norms.

The classroom norms developed during this course represented characteristics of an atmosphere that reflected respect and support for all class members. The positive atmosphere encouraged students' participation in the interactive activities that were used the majority of the time for instruction throughout the course. The relationship between the positive emotional climate, high levels of student participation, and small class size support the research of Fassinger (2000) described previously in the present study.

Graphing Calculator Use

The belief that the graphing calculator could be used to facilitate the teaching and learning of college algebra was demonstrated by the integrated use of the tool during instruction starting with the first day of class. The proactive nature of her instructional plans was demonstrated several ways. On the first day of class, the majority of the classroom norms identified was initiated by her explicit expectations for students' behavior.

Integrated instructional activities with the graphing calculator were carefully sequenced so that instructional procedures taught for graphing calculator use would be already learned resulting in seamless use in later lessons. Although integrated graphing calculator instruction was the most intense during Unit 1, the majority of students reported using the calculator for more items on other unit tests, even though the tool was used less during instruction for those units. Throughout the semester, Mrs. A's consistent use of practices integrating graphing calculator use with mathematics instruction along with support materials resulted in students' independent use of the tool during class activities and major assessments. The relationship between calculator instruction during integrated activities and students' independent use of the calculator has been reported in research literature (Herman, 2007). Similarly, Guin and Trouche (1999) suggested that the additional instructional time taken to emphasize efficient graphing calculator techniques may facilitate students' efficient use of the tool and save time during later activities.

Evidence of students' independent use of the graphing calculator was significant since the majority of students had never used the tool before this course. During major assessments, the majority of students began to use graphing calculator solution strategies more frequently as their knowledge of calculator techniques grew relying less on paper and pencil methods and use of the tool to just verify their answers. However, this finding is different from that of Herman (2007) based on a case study of 38 students in a 10-week college algebra course in which students' showed a continued preference for symbolic solution methods as their primary solution strategy even though they were knowledgeable and capable of using the calculator for graphical and tabular approaches. Students indicated that they thought the symbolic method was the most valid approach because the instructor always did problems by hand first then used the graphing calculator for graphical and tabulator approaches as back up methods.

Herman (2007) reasoned that students did not view the graphing calculator as an integral part of the learning process of learning mathematics but rather viewed it as a procedural tool or computational device used to verify answers and that they may have benefited from having additional time to master calculator procedures. Additionally, four reasons given to explain the influences underlying students' choice of solution strategies and graphing calculator use included (1) student perception of instructor's beliefs about the value of given methods, (2) the uses of representations modeled by the instructor; (3) the efficiency of a representation to produce an answer, and (4) students' perception of proper mathematical methods.

The four reasons given by Herman (2007) may be used to explain students' use of the solution approaches for this study. The majority of students' who increased their use of graphing calculator solution strategies may have been influenced by their perception of Mrs. A's beliefs about the value and utility of the graphing calculator solution approaches, her explicit expectations regarding students use of the calculator, and by the way the representations were modeled during instruction. Students' use of graphing calculator solution approaches during assessments indicated that sufficient instruction and practice using the tool provided the support and experiences required to help students master calculator techniques and to recognize the utility of the solution approaches offered by the technology. Although a few students preferred to use symbolic methods over calculator solution approaches, the reason would not be that the symbolic method was taught first as in the Herman study.

Discussion: Second Finding

Balanced Calculator Approaches

The instructional strategies modeled and used by Mrs. A during the course were similar to the balanced approach to graphing calculator use advocated by Waits and Demana (1998) in their work with visualization of mathematics to enhance the teaching and learning of mathematics. A summary of their threefold approach includes (1) solve problems analytically using traditional paper and pencil algebraic methods then support the result using a graphing calculator, (2) solve problems using a graphing calculator and then confirm the result analytically using traditional paper and pencil algebraic methods, and (3) solve problems using a graphing calculator because traditional methods are too tedious, time consuming, or not possible. The varied approaches to solving problems emphasize flexibility and appropriateness when selecting a solution method to solve a particular type of problem as modeled by Mrs. A during instructional activities.

Interactive Facilitator

The instructor's knowledge of the graphing calculator resulted in her skillful and varied use of the tool for instructional purposes. As an external representational system, the calculator provided dynamic and interactive media that facilitated exploration of mathematical concepts, the use of and linking among multiple representations of mathematical ideas, and collaboration among members during class activities. Similarly, the capabilities for using the graphing calculator to facilitate varied interactive activities has been identified and described by previous research.

Hennessy et al. (2001) describes the facilitating features offered through graphing calculator use as a “cognitive prop” facilitating translation between multiple representations, a “mediating tool” facilitating collaboration through its use as a constant external reference object, and a “essential participant” facilitating through checking roles that help structure thinking and transform mathematical activity.

Therefore, the interactive facilitating roles provided through graphing calculator use offered opportunities for students’ personal and collaborative engagement in dynamic learning experiences. Such learning opportunities promote students development of intellectual autonomy. Intellectual autonomy, described by Yackel (2000, August) in reference to mathematics, is the reasoned judgments students make about the way they interact mathematically and about the contributions they make to class interactions. Promotion of students’ intellectual autonomy leads to the development of mathematical power.

Calculator Use

Although Mrs. A used different representations extensively to promote students’ conceptual understanding of topics, the graphing calculator was used the majority of time for functional concepts and calculator-intensive skill approaches. For functional concepts, the calculator facilitated making connections between and among algebraic, numerical, and graphical representations by quickly and easily providing a linkage among the representations and access to calculation features. Visual and numerical solution approaches were used as alternatives to paper and pencil methods for topics and skills not quickly attainable using traditional algebraic methods. Data analysis included the graphing of plots, regression equations, and statistical analysis. The calculator was also used for varied computations and verification of work completed by paper and pencil.

Graphing calculator use in this study supports the five patterns of graphing calculator use identified by Doerr and Zangor (2002) in their case study of a pre-calculus class: computational tool, transformational tool, data collection and analysis, visualization, and checking. They concluded that the meanings of the graphing calculator uses were co-constructed by the teacher and the students. In the present study, Mrs. A led student interactive discussions during activities in which the graphing calculator was used and frequently used formative assessments to monitor students' understanding of the representations being viewed and studied.

High Cognitive Delivery

Analysis of M-SCOPS data for the course units indicated a positive relationship between the instructor's delivery of high level of cognitive information and the use of graphing calculator. The interactive and dynamic features of the graphing calculator facilitated quick and easy access to multiple representations of concepts that enabled delivery of instruction at complex cognitive levels. During the integrated graphing calculator activities, student interactive discussion approaches were used.

Students' responses to lesson questionnaires completed immediately after each instructional lesson indicated that graphing calculator use generally enhanced their understanding of the lessons and facilitated class interactions that enhanced their understanding. The students' positive responses indicated that the instructional scaffolding level used by Mrs. A was appropriate for supporting and advancing their understanding during these activities. The finding supports the research of Henningsen and Stein (2002) concerning factors that are associated with maintaining student engagement at high cognitive levels when doing mathematics.

Henningsen and Stein (2002) analyzed 58 mathematical tasks used in middle school classrooms involved in the Quantitative Understanding: Amplifying Student Achievement and Reasoning project. They found five primary factors that would frequently be expected to be in place to influence and to maintain student engagement in mathematical tasks at high cognitive levels (1) building on students' prior knowledge, (2) scaffolding, (3) allocating sufficient amount of time, (4) modeling of high-level performance, and (5) focusing on explanation and understanding. These factors were represented in the present study and exemplify the importance of the instructor's strategic instructional design and implementation and the influence of the classroom norms on students' interactions and sustained involvement in high level mathematical tasks.

Discussion: Third Finding

Students' responses to lesson and assessment questionnaires completed immediately after each lesson or major assessment indicated favorable responses to graphing calculator use for both lessons and assessments with few exceptions. Although the majority of the students had never used the graphing calculator before the course, analysis of students' responses indicated the tool was beneficial for enhancing their understanding of lessons and facilitating class interactions. All students chose to use the graphing calculator for major assessments indicating favorable uses of the tool: feeling confident using the tool, knowing how to use the tool, understanding why certain key strokes were used, making the test easier, saving time taking the test, and improved test performance.

Positive Responses to Calculator Use

The positive students' responses support the findings of the Hennessey et al. (2001) study described previously. The majority of the students in the Hennessey et al. study responded positively to questionnaire items completed at the end of the course related to a belief that the graphing calculator was valuable for learning mathematics, helping them understand the link between representations, making doing math easier.

No Calculator Experience

In the present study, students who had no prior experience with the graphing calculator were most likely to indicate confusion during lessons and forgetting how to work problems on tests. These students may have benefited from knowing calculator procedures before the course so they would not have to learn how to use the tool along with the course material. On the other hand, they were also the most likely to indicate that the graphing calculator helped ease stress and test anxiety and that they believed its use would help them successfully complete the course.

Calculator Experience

Previous experiences with graphing calculator use did not necessarily equate with knowledgeable use of the tool. Being able to use calculators during a course does not necessarily infer that the tool was effectively utilized. Some of the students who had access to graphing calculators in a previous mathematics class stated they still did not know much about how to use it. Research previously described (Hennessy et al., 2001), supports the claim that students need to be taught how and when to use the calculator, what the tool is doing and why, explicit instruction on representations and linkages produced, and information concerning constraints and limitations to promote appropriate and knowledgeable utility of the tool.

One Student's Experience

One student successfully completed the course with an A even though she had previously dropped three college algebra classes because of failing grades. When turning in her lesson questionnaire the first day of class, she told me that this was only the second math class she had taken that she wasn't upset by the time the class was over. Recently diagnosed with a math disability called dsycalculis, she described her frustrations in trying to learn math since the first grade and just didn't "get it" the way the other college algebra teachers taught.

She could not get equations to make sense and felt the graphing calculator would help with her math difficulties. She remarked, "I think I will be able to learn more in this class. (Mrs. A) doesn't take it for granted that we know and understand things." In an interview her last day of class, I asked, "What things did this teacher do that helped you be successful?" She replied, "I think it is the way she explains things. She explains it different ways using different methods in a way that's easy to understand. Then she let's you decide which method to use to work the problems. She shows you how to use the calculator and let's you decide if you want to use it or not."

This student's responses provide additional support for claims made previously that Mrs. A proactively sought to relieve students' stress in the way she interacted with the students, appropriately building on their prior knowledge, scaffolding their understanding to higher levels, and encouraging autonomy in doing mathematics.

Additionally, in response to students with challenges in learning mathematics, Hennessy et al. (2001) suggested that the use of the graphing calculator may reduce the cognitive load when doing mathematics by taking over the mechanics of the translation processes enabling focus on understanding the concept.

Recommendations

Suggestions for Practice

The findings of this study have been used to generate suggestions for teaching practices when using an integrated instructional approach with graphing calculators. Strategic planning of instruction and activities is essential to maximize the effectiveness of the tool for enhancing instruction and students' understanding of certain topics and skills. Proactive instruction is recommended for the purposes of saving time in later lessons when the tool is used. Written directions should be provided to support students' use of the instrument along with opportunities to view an external projected image of the instructor's calculator screen.

Educators need to be aware that how they use the graphing calculator has an influence on how students' perceive that the tool should be used. A list of suggestions for using graphing calculators in the classroom has been provided in Table 18. Using varied strategies is recommended when using the calculator so that students become flexible and efficient in their use of the tool. For example, depending on the instructional

Table 18
Suggested Practices for Classroom Graphing Calculator Use

#	Suggested practice
1	Each student has a graphing calculator for his/her personal use
2	Graphing calculators are on students' desks available for immediate use
3	For initial skill development, use handouts with self-directing and self-checking support
4	When applicable, give time for personal review of the activity before direct instruction
5	Provide visual support for the location of keys and key stroke sequences
6	Use a device to project the instructor's screen for a shared external image
7	Provide direct instruction on how and when to use the tool and the constraints involved
8	Provide guided practice when using new graphing calculator skills
9	Teach graphing calculator procedures integrated with mathematics instruction
10	Assist students' development of a peer support system by providing time for them to ask each other questions and to check their peers' use of the tool
11	Give ample time for inquiries, discussion, practice, and collaboration
12	Provide explicit instruction linking the different representations used
13	Assess students' understanding about what they are doing and why they are doing it

objective, use the calculator to verify work completed by algebraic methods, at other times use algebraic methods to verify work completed with the calculator, and use calculator approaches exclusively for problems that are challenging to complete using algebraic methods. Teach students multiple solution approaches so that students have the opportunity to select the method that is most effective for the problem at hand or that makes the most sense to them.

Although teachers cannot control over-reliance on the graphing calculator by students, they can create assessments in which use of the tool is restricted to help students focus on the skills being taught as opposed to just learning calculator procedures or keystrokes sequences without understanding the underlying processes the tool is using to produce the representation. Quizzes are recommended for assessing students understanding of concepts that the use of the calculator may mask. Students' concept development can then be assessed to ensure that the students are learning the concept as opposed to just calculator procedures. However, graphing calculator availability is recommended for tests and other major assessments.

Limitations of the Study

The participants for this case study were a particular group of individuals and the complex interactions that took place in this classroom were unique for that setting. Therefore, the way the findings for this study were derived may not be replicated and are best viewed in light of prior research and recommended educational practices.

Equity Issues

Although not a major focus of this study, the research finding that the students taking remedial college mathematics courses were not given access to graphing calculator technology raises some equity concerns. If reform strategies such as the appropriate use of graphing calculators are shown to enhance students' understanding and promote their achievement, then why were these students not given the opportunity to use the tool in previous courses? Furthermore, the majority of the students taking the classes were of non-traditional college age trying to advance their mathematical knowledge to be able to participate in a college level math class. These students deserve the opportunity to use a tool that has the potential to enhance their understanding of mathematics and to enhance their class performance.

Recommendations for Further Study

In this study, I was limited in being able to view students' external representation productions on their graphing calculators during collaborative activities and discussions to determine the level at which they were responding to the cognitive receiving level from the instructor. Use of a TI-Navigator system, a wireless communication between students' TI graphing calculatos and the teacher's computer, would enable real-time formative assessment by displaying all students screen shots instantly, permitting a real-time formative assessment of their representations reflective of their comprehension at various times in the lesson. The display of the students' screen shots could be saved by the teacher to be analyzed later by the researcher. Using the system, all students' engagement and understanding could be assessed and not just the students who respond during discussions thus providing a more accurate analysis of all students' responses.

An additional recommendation for study is an analysis of students' tests. In this study, all students chose to use the graphing calculator to some extent on major tests. Their responses to the assessment questionnaires indicated their reflections about the tool during the assessment. However, students were not required to show work to support their answers on tests so an analysis of their tests to determine their choice of solution method for each problem was not deemed beneficial.

Questions about how the calculator was used on tests were not addressed. For what type of problems did the student chose to use the graphing calculator and why was it chosen for that item? What experiences resulted in influencing the student to use the tool for that problem? What impact did previous instruction, present instruction, peer interactions, or personal investigations have on how the student chose to use the tool?

Answers to these questions may provide insight to the relationship between a student's use of the tool for specific problems and the experiences that influenced the decision. Educators can benefit from knowing about the kinds of experiences that influence a student to use the graphing calculator so that the tool is utilized appropriately without misuse. Therefore, an investigation of the reasons behind a student's selection of a particular solution method over other approaches when a graphing calculator is accessible is recommended for further study.

Summary

This chapter presented information on how the present study's findings both supports and advances prior research. The research findings illustrate how graphing calculator use as an integrated part of the classroom norms facilitates interactions that provide opportunities for enhanced student learning and performance. The study also addressed the call for additional research on ways to promote students' efficient use of the calculator by providing descriptions of the instructional strategies used by the instructor to promote students' knowledgeable utilization of the tool. Moreover, concerns about students' over-reliance on the graphing calculator have been addressed by providing examples of strategies designed to discourage use of the tool without understanding.

Additionally, the implications of the study's findings on educational issues have been addressed in this chapter. Suggestions have been given on how instructional strategies can be designed to encourage and to support students' graphing calculator use. Further research on the reasons underlying students' chose of solution approaches have been suggested to give educators insight to the kind of instructional experiences that influence students' decisions. Students in all college mathematic classes should be given opportunities to become knowledgeable users of the graphing calculator in equitable learning environments designed to promote students' learning through dynamic and interactive experiences.

REFERENCES

Abrams, J. P. (2001). Teaching mathematical modeling and the skills of representation. In A. A. Cuoco & F. R. Curcio (Eds.), *The roles of representation in school mathematics: 2001 NCTM yearbook* (pp. 269-282). Reston, VA: National Council of Teachers of Mathematics.

American Mathematical Association of Two-Year Colleges (AMATYC) (2006). *Beyond crossroads: Implementing mathematics standards in the first two years of college.* Washington, DC: Author. Retrieved June 5, 2007, from http://beyondcrossroads.com

Bloom, B. S. (1976). *Human characteristics and school learning*. New York: McGraw-Hill.

Burrill, G. (1992). The graphing calculator: A tool for change. In J. T. Fey & C. R. Hirsch (Eds.), *Calculators in mathematics education* (pp.14-22). Reston, VA: National Council of Teachers of Mathematics.

Burrill, G., Allison, J., Breaux, G., Kastberg, S., Leatham, K., & Sanchez, W. (2002). *Handheld graphing technology in secondary mathematics: Research findings and implications for classroom practices.* Dallas, TX: Texas Instruments.

Cassity, C. L. (1997). *Learning with technology: Research on graphing calculators*. (Report No. IR018421). Albuquerque, NM: National Convention of the Association for Educational Communications and Technology. (ERIC Document Reproduction Service No. ED409880)

Cooney, T. J., & Shealy, B. E. (1997). On understanding the structure of teachers' beliefs and their relationship to change. In E. Fennema & B. S. Nelson (Eds.), *Mathematics teachers in transition* (pp. 19-53). Mahwah, NJ: Erlbaum.

Coulombe, W. N., & Berenson, S. B. (2001). Representations of patterns and functions: Tools for learning. In A. A. Cuoco & F. R. Curcio (Eds.), *The roles of representation in school mathematics: 2001 NCTM yearbook* (pp. 166-172). Reston, VA: National Council of Teachers of Mathematics.

Cuoco, A. A. (2001). Preface. In A. A. Cuoco & F. R. Curcio (Eds.), *The roles of representation in school mathematics: 2001 NCTM yearbook,* (pp. ix-xiii). Reston, VA: National Council of Teachers of Mathematics.

Doerr, H. M., & Zangor, R. (2000). Creating meaning for and with the graphing calculator [Electronic version]. *Educational Studies in Mathematics, 41*, 143-163.

Fassinger, P. A. (2000). How classes influence students' participation in college classrooms [Electronic version]. *Journal of Classroom Interaction, 35*(2), 38-47.

Friedlander, A. & Taback, M. (2001). Promoting multiple representations in algebra. In A. A. Cuoco & F. R. Curcio (Eds.), *The roles of representation in school mathematics: 2001 NCTM yearbook* (pp. 173-185). Reston, VA: National Council of Teachers of Mathematics.

Goldin, G. A. (2002). Representation in mathematical learning and problem solving. In L. D. English (Ed.). *Handbook of international research in mathematics education* (pp. 197-219). Mahwah, NJ: Erlbaum.

Goldin, G. A. (2003). Representation in school mathematics: A unifying research perspective. In J. Kilpatrick, W. G. Martin, & D. Schifter (Eds.), *A research companion to principles and standards for school mathematics* (pp. 275-285). Reston, VA: National Council of Teachers of Mathematics.

Goldin, G., & Shteingold, N. (2001). Systems of representations and the development of mathematical concepts. In A. A. Cuoco & F. R. Curcio (Eds.), *The roles of representation in school mathematics: 2001 NCTM yearbook* (pp. 1-23). Reston, VA: National Council of Teachers of Mathematics.

Goos, M. (2004). Learning mathematics in a classroom community of inquiry. *Journal for Research in Mathematics Education, 35*, 258-291.

Goos, M., Galbraith, P., Renshaw, P., & Geiger, V. (2000). Reshaping teacher and student roles in technology-enriched classrooms [Electronic version]. *Mathematics Education Research Journal, 12*, 303-320.

Goos, M., Galbraith, P., Renshaw, P., & Geiger, V. (2003). Perspectives on technology mediated learning in secondary school mathematics classrooms [Electronic version]. *The Journal of Mathematical Behavior, 22*(1), 73-89.

Guin, D., & Trouche, L. (1999). The complex process of converting tools into mathematical instruments: The case of calculators [Electronic version]. *International Journal of Computers in Mathematical Learning, 3*, 195-227.

Heid, M. K. (2003). Theories for thinking about the use of CAS in teaching and learning mathematics. In J. T. Fey, A. Cucco, C. Kieran, L. McMullin, & R. M. Zbiek (Eds.). *Computer algebra systems: In secondary school mathematics education* (pp. 33-52). Reston, VA: National Council of Teachers of Mathematics.

Heller, J. I., Curtis, D. A., Jaffe, R., & Verboncoeur, C. J. (2005). *Impact of handheld graphing calculator use on student achievement in algebra I.* Retrieved July 1, 2006, from http://education.ti.com/sites/US/downloads/pdf/heller_grcalcreport_2005.pdf

Hennessy, S., Fung, P., Scanlon, E. (2001). The role of the graphic calculator in mediating graphing activity [Electronic version]. *International Journal of Mathematical Education in Science and Technology, 32*, 267-290.

Henningsen, M. & Stein, M. K. (2002). Supporting students' high-level thinking, reasoning, and communication in mathematics. In J. Sowder & B. Schappelle (Eds.), *Lessons learned from research* (pp. 27-35). Reston, VA: National Council of Teachers of Mathematics.

Herman, M. (2007). What students choose to do and have to say about use of multiple representations in college algebra [Electronic version]. *The Journal of Computers in Mathematics and Science Teaching, 26*(1), 27-54.

Hiebert, J., & Carpenter, T. P. (1992). Learning and teaching with understanding. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 65-97). New York: Macmillan.

Howard, J. R., & Baird, R. (2000). The consolidation of responsibility and students' definitions of situation in the mixed-age college classroom [Electronic version]. *The Journal of Higher Education, 17,* 700-721.

Jones, P. L. (1995). Realizing the educational potential of the graphics calculator. In The McKenzie Group (Eds.). *Handheld technology and student achievement: A collection of publications* (pp. 52-55). Dallas, TX: Texas Instruments.

Kaput, J. J. (1989). Linking representations in the symbol system of algebra. In C. Kieran & S. Wagner (Eds.), *A research agenda for the teaching and learning of algebra* (pp. 167-194). Reston, VA: National Council of Teachers of Mathematics.

Kaput, J. J. (1992). Technology and mathematics education. In D. Grouws (Ed.), *Handbook on research in mathematics teaching and learning* (pp. 515-556). New York: Macmillan.

Kazemi, E., & Stipek, D. (2002). Motivating students by teaching for understanding. In J. Sowder & B. Schappelle (Eds.). *Lessons learned from research* (pp. 17-22). Reston, VA: National Council of Teachers of Mathematics.

Mariotti, M. A. (2002). The influence of technological advances on students' mathematics learning. In L. D. English (Ed.). *Handbook of international research in mathematics education* (pp. 695-723). Mahwah, NJ: Erlbaum.

Mathematical Association of America (MAA) (2004). *Undergraduate programs and courses in mathematics sciences: CUPM curriculum guide 2004. A report of the Committee on the Program.* Washington, DC: Author.

Merriam, S. B. (1998). *Qualitative research and case study applications in education: Revised and expanded from case study research in education.* San Francisco: Jossey-Bass.

National Council of Teachers of Mathematics (NCTM) (1991). *Professional standards for teaching mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics (NCTM) (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

Pesek, D. D., & Kirshner, D. (2002). Interference of instrumental instruction in subsequent relational learning. In J. Sowder & B. Schappelle (Eds.), *Lessons learned from research* (pp. 101-107). Reston, VA: National Council of Teachers of Mathematics.

Sawada, D., Piburn, M. D., Judson, E., Turley, J., Falconer, K., Benford, R., & Bloom, I. (2002). Measuring reform practices in science and mathematics classrooms: The reformed teaching observation protocol [Electronic version]. *School Science & Mathematics, 102*, 245-254.

Shulman, L. S. (1986). Paradigms and research programs in the study of teaching: A contemporary perspective. In M. Wittrock (Ed.), *Handbook of research on teaching* (pp. 3-36). New York: MacMillan.

Smith, K., & Shotsberger, P. (1997). Assessing the use of graphing calculators in college algebra: Reflecting on dimensions of teaching and learning [Electronic version]. *School Science & Mathematics, 97,* 368-377.

Stuessy, C. (2005). Theoretical framework: Multiple representations, modeling, and modeling practice. In C. Stuessy, J. Parrott, & A. Foster (Eds.), *Looking inside: videotape analysis of classroom learning environments* (pp. 13-20). Paper presented at the pre-conference workshop of the National Association for Research in Science Teaching, Dallas, TX.

Sullivan, M. (2004). *College algebra* (7th ed.). Boston: Prentice-Hall.

Thompson, A. G. (1992). Teachers' beliefs and conceptions: A synthesis of the research. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 127-146). New York: Macmillan.

Waits, B. K., & Demana, F. (1998). *The role of graphing calculators in mathematics reform.* Retrieved July 1, 2007, from http://www.math.ohio-state.edu/~waitsb/papers/roleofgraphcalc.pdf

Wilson, M. (1990). Investigation of structured problem solving items. In G. Kulm (Ed.), *Assessing higher order thinking in mathematics* (pp. 137-203). Washington, DC: American Association for the Advancement of Science.

Yackel, E. (2000, August). *Creating a mathematics classroom environment that fosters the development of mathematical argumentation.* Paper presented at the meeting of the Ninth International Congress of Mathematical Education, Tokyo/Makuhari, Japan. Retrieved July 1, 2006, from http://www.nku.edu/~sheffield/eyackel.html

Yackel. E., & Cobb, P. (1996). Sociomathematical norms, argumentation, and autonomy in mathematics. *Journal for Research in Mathematics Education, 27*, 457-477.

APPENDIX A

M-SCOPS SYSTEM

M-SCOPS: Scripting Sheet

Teacher______________________________ Class_________________________________ Lesson______________________________

Grade________________________________Date__________________________________ Recorder____________________________

Description of Learning Goals: Include TEKS, Objectives on Board, and Verbal Explanation

SEG	BEg	End	# Min	%	R & D	P & I	What the Teacher Is Doing	What Information (Content) the Students Are Receiving	◆ S	● M	■ P	What the Students Are Doing	◆ S	● M	■ P
1															
2															
3															

Note. Modified from Stuessy (2005). Theoretical Framework: Multiple Representations, Modeling, and Modeling Practice. Used with permission.

M-SCOPS: Codes

Codes, Descriptions, and Examples of Instructional Scaffolding Strategies

R&D[1]	P&I[2]	Description	Examples
5	1	Individual students are directed to listen as the teacher or another student talks to entire group; students are directed to read or do seat work	Direct instruction models; lecture, silent reading, independent practice, seat work
4	2	Individual students respond orally or in writing to questions asked by the teacher, in whole group	Teacher-led recitation; question and answer; discussion led and directed by the teacher
3	3	Students in pairs or small groups work together under the teacher's supervision – with discussion; all groups do basically the same task	Student discussion in groups; task completion; verification laboratories, cooperative learning models
2	4	Groups and/or individual students work on different tasks with some choice options; loosely supervised by the teacher	Student- or group-initiated work on choices or options provided by the teacher; "centers" or learning stations
1	5	Students in pairs or small groups discuss, design, and/or formulate their own plans for working in class on a specified task; minimal supervision	Open-ended laboratory or project work
0	6	Individuals or groups carry out their own work independently; minimal supervision	Individualized laboratory or project work

Note. [1]R&D refers to Reception and Direction. [2]P&I refers to Performance and Initiative

Note. Stuessy (2005). Theoretical Framework: Multiple Representations, Modeling, and Modeling Practice. Used with permission.

M-SCOPS: Representation Category Codes

Codes for Actions of Students with Multiple Representations in Receiving and Performing

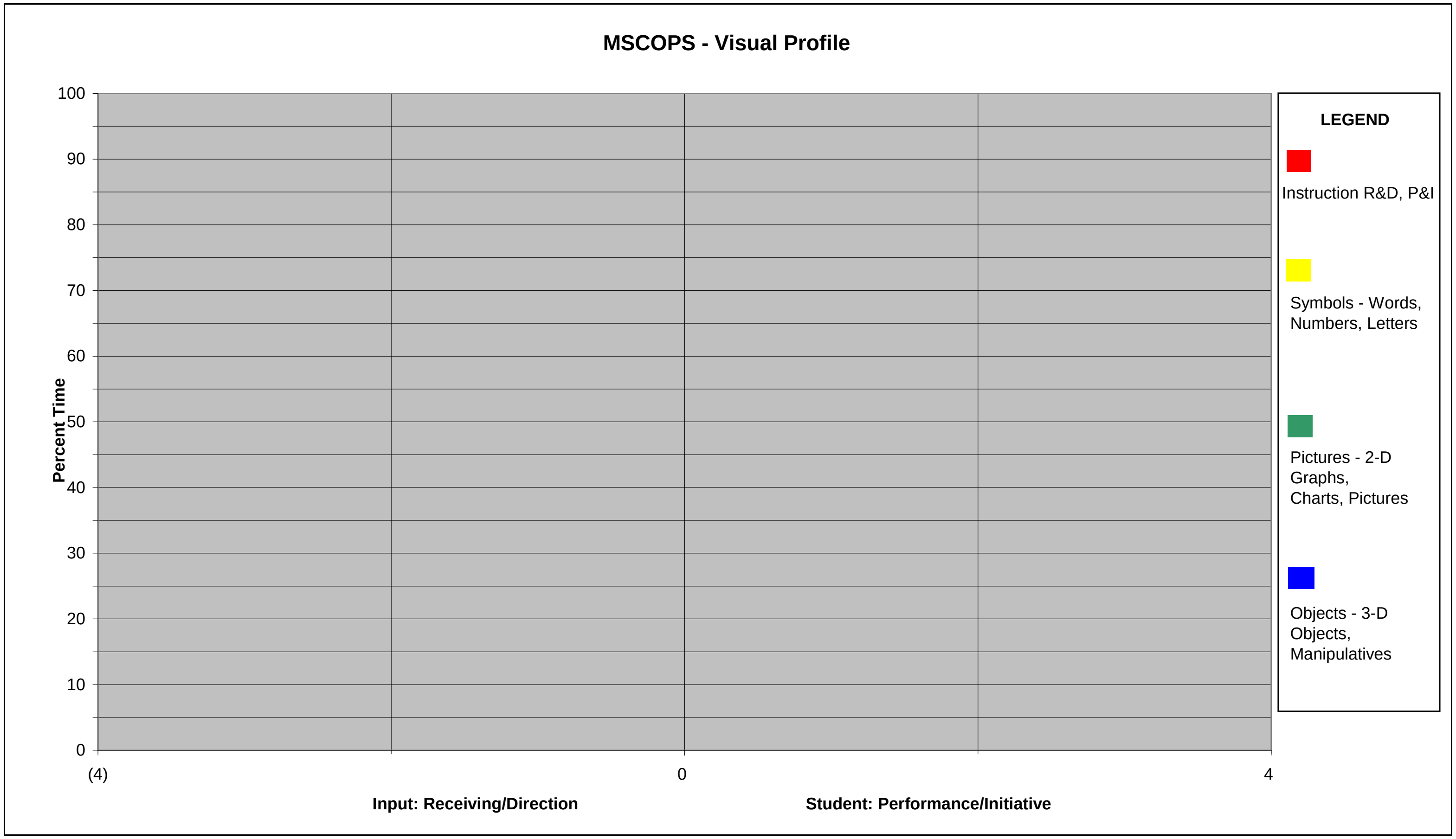
Action Category	Level (Code)	Input	Action
Attend	1	External or superficial features, attributes, challenges to perform a level 1 action	Listen to, attend to, observe, watch, read, view
Replicate	2	Examples, identifications, descriptions, explanations, clarifications, calculations, documentations, duplications, measurements, reproductions, demonstrations, algorithms, challenges to perform a level 2 action	Recall, remember, list, tell, identify, label, collect, examine, manipulate, name, tabulate, identify, give examples, describe, explain, clarify, calculate, document
Rearrange	3	Comparisons, groupings, sequences, patterns, rearrangements, balancing, classifications, disassembled parts of a whole; processes of putting parts of a whole together, challenges to perform a level 3 action	Compare, group, put in order, rearrange, identify a pattern, paraphrase, balance, classify, identify parts of a whole, assemble parts to make a whole, disassemble parts of a whole
Transform	4	Alternative points of view, Distinguishing one from another, differentiations, arrangements of complex parts into a whole system, transformations, changes, challenges to perform a level 4 action	Represent symbolically or pictorially, experiment, interpret, contrast, apply, modify, make choices, distinguish, differentiate, transform, change, arrange complex parts into a system

M-SCOPS: Representation Category Codes Continued

Action Category	Level (Code)	Input	Action
Generate	6	Analyses, evaluations, summaries, conclusions, abstract models and representations, problem scenarios, challenges to perform a level 6 action	Express conceptual models, define relationships in new systems, generalize, recommend, evaluate, assess, conclude, design, generate a problem, solve a problem of one's own generation

Note. Modified from Stuessy (2005). Theoretical Framework: Multiple Representations, Modeling, and Modeling Practice. Used with permission.

M-SCOPS: Electronically Created Visual Profile Form



Note. Stuessy (2005). Theoretical Framework: Multiple Representations, Modeling, and Modeling Practice. Used with permission.

APPENDIX B

QUESTIONNAIRES

Teacher Questionnaire

Teacher: ____________________ Date: _____________ Code: ______________

TEACHER QUESTIONNAIRE: LESSON GOALS & REFLECTIONS FOR INTEGRATED INSTRUCTION USING GRAPHING CALCULATORS (GC)

Learning Objective(s):

Materials:

Class Organization:

Instructional Use of GC:

Students' Use of the GC:

Assessment:

Concerns Related to GC Use:

Teacher Questionnaire Continued

TEACHER'S REFLECTIONS

Related to Instructional Use of GC:

Related to Students' Use of GC:

Other Comments or Reflections:

Student Questionnaire: Initial Background Information

Name: _______________ Code: _______ Date: _______________

Student Background Information & Graphing Calculator Experience

Part I: Background Information

Directions: Please circle or answer the appropriate response to the items below.

Gender: Male Female

Ethnicity: African American, Hispanic, Caucasian, Native American, Asian/Pacific Islander, Other____

Graphing Calculator Experience: I have used a graphing calculator in a mathematics class. YES NO

If you circled NO, please skip to Part III on the back of this page. If you circled YES, please list the type of graphing calculator(s) you used.

Student Questionnaire: Initial Background Information Continued

Part II: Self-Report based on Previous Experiences with Graphing Calculators

Directions: Please respond to the following statements by indicating your agreement or disagreement with each statement by circling the most appropriate response according to the following scale:

1 – Strongly Disagree (SD); 2 – Disagree (D); 3 – Undecided (U); 4 – Agree (A); 5 – Strongly Agree (SA)

	SD	D	U	A	SA
1.I am confident in my ability to use a graphing calculator.	1	2	3	4	5
2.I am knowledgeable about using a graphing calculator.	1	2	3	4	5
3.I use the graphing calculator to help me connect ideas and mathematical representations.	1	2	3	4	5
4.Graphing calculator use can stimulate and enhance discussions related to certain math topics.	1	2	3	4	5
5.I use the graphing calculator to explore and investigate my ideas and the concepts discussed in class.	1	2	3	4	5
6.I would prefer not to use a graphing calculator in class.	1	2	3	4	5
7.The graphing calculator has value for teaching and and learning mathematics.	1	2	3	4	5

Student Questionnaire: Initial Background Information Continued

Part III: Previously Completed Math Courses and Graphing Calculator Access

Directions: Please circle the appropriate responses to math courses completed and indicate if you used graphing calculators during the course. If you used graphing calculators during a course, estimate the percent of time they were used in the class compared to the whole course.

Course	Completed	Access to Graphing Calculator	Estimate the Percent of Time Graphing Calculator were Used
High School			
Algebra I	No / Yes	No / Yes	____________
Geometry	No / Yes	No / Yes	____________
Algebra II	No / Yes	No / Yes	____________
Math Models	No / Yes	No / Yes	____________
Pre-Calculus	No / Yes	No / Yes	____________
Calculus	No / Yes	No / Yes	____________
Statistics	No / Yes	No / Yes	____________
Other	________	No / Yes	____________
College			
Introductory Algebra	No / Yes	No / Yes	____________
Intermediate Algebra	No / Yes	No / Yes	____________
Trigonometry	No / Yes	No / Yes	____________
Pre-Calculus	No / Yes	No / Yes	____________
Other	________	No / Yes	____________

I appreciate the time you have taken to complete this survey. All the information you have provided is confidential. Please feel free to ask me any questions you may have regarding your participation in this research project. *-Sally Gerren, Researcher*

Student Lesson Questionnaire

Name: _____________ Code: ________________ Date: ______________

STUDENT LESSON QUESTIONNAIRE: GRAPHING CALCULATOR (GC) USE

Directions: Please provide your responses to the following questions or prompts.

1. Did you use the GC during today's lesson? (Circle one) YES NO

2. If yes, please approximate the amount of time you used the GC today in class. _____

3. Please approximate the amount of time you used the GC to do homework or to study outside of class since the last class session. _______________

4. Did you use the GC for anything else besides the work for this class? ____________

5. Circle the best response that describes how beneficial the use of the GC was in enhancing your understanding of today's lesson.

   Very Beneficial **Moderately Beneficial** **Not Beneficial**

6. Circle the response that **best** represents how beneficial the GC was in stimulating and/or supporting discussion and/or collaboration that enhanced your understanding of the mathematics related to today's lesson.

   Very Beneficial **Moderately Beneficial** **Not Beneficial**

7. Circle the response that **best** represents how the use of the GC overhead projector screen was beneficial in helping you follow along during today's lesson.

   Very Beneficial **Moderately Beneficial** **Not Beneficial**

8. Circle **one** of the following phrases to finish this statement: I know the keystrokes necessary to complete today's exercises and/or problems . . .
   a) **With** an understanding of the mathematics involved.
   b) **Without** understanding the mathematics involved.
   c) I am **confused** about the keystrokes to use.

9. Please finish the following phrase: Using the GC today ___________________

   ____

10. Please use the back of this paper to add any additional comments or reflections.

Thank you for taking the time to complete this survey. All the information you have provided is confidential. Please feel free to ask me any questions regarding your participation in this research study. *-Sally Gerren, Researcher*

Student Assessment Questionnaire

Name: ____________________ Code: __________________ Date: ____________________

ASSESSMENT QUESTIONNAIRE: STUDENT'S GRAPHING CALCULATOR USE

Directions: Please provide your responses to the following questions or prompts.

1. Did you use the graphing calculator during today's quiz/test? *(Circle one)* YES NO
2. If yes, please record the number of problems you used the graphing calculator to help you work or solve. _____________
3. Please finish this statement: Using the graphing calculator during today's quiz/test ______________________________

____

Indicate your agreement or disagreement with each statement by circling the most appropriate response according to the following scale: 1 – Strongly Disagree (SD); 2 – Disagree (D); 3 – Undecided (U); 4 – Agree (A); 5 – Strongly Agree (SA)

		SD	D	U	A	SA
4.	I was confident in using the calculator during today's test.	1	2	3	4	5
5.	I was not sure about how to use the calculator during the test.	1	2	3	4	5
6.	I feel like I just punched keys without understanding why.	1	2	3	4	5
7.	I think using the calculator made the test easier to complete then then using just paper and pencil.	1	2	3	4	5
8.	I worked the problems using paper and and pencil and then used the calculator to check my answers.	1	2	3	4	5
9.	Using the calculator saved time compared to just paper and pencil and pencil to complete the test.	1	2	3	4	5
10.	I feel that being able to use the graphing calculator for today's test will result in a better grade than I would have had with just paper and pencil.	1	2	3	4	5

11. Please record any additional advantages for using the graphing calculator for this assessment.

12. Please record any additional disadvantages for using the graphing calculator for this assessment.

13. Please record any additional comments or reflections. Use the back on this paper if necessary.

Thank you for taking the time to complete this survey. All the information you have provided is confidential. Please feel free to ask me any questions regarding your participation in this research study. *-Sally Gerren, Researcher*

APPENDIX C

CONSENT FORMS

Teacher Consent Form

TEACHER CONSENT FORM

A CASE STUDY: THE RELATIONSHIP BETWEEN THE USE OF GRAPHING CALCULATORS AND THE DEVELOPMENT OF CLASSROOM NORMS IN A COLLEGE ALGEBRA COURSE

I have been asked to participate in a research study for the purpose of exploring the relationship between the use of graphing calculators by members of a college algebra class and the classroom norms that develop that give meaning and purpose to the instrument's use. This study is intended to fulfill the dissertation requirement for completion of the PhD degree program for the principal investigator, Sally Gerren. I was selected to be a possible participant because I am the teacher of the college algebra class that was chosen for the inquiry. A total of twenty to thirty people have been asked to participate in this study.

If I agree to be in this study, I will be asked to complete a short questionnaire each class session, allow the investigator to observe class activities, and participate in informal interviews as needed to clarify information about an observation or a questionnaire. My classroom participation and/or interviews may be audio taped to preserve accuracy in the collection of data. I will be informed when audio taping is to occur. This study will be conducted throughout the course's duration, approximately 14 weeks. I will be asked to complete a questionnaire for each class period to provide information about the use of the graphing calculator during class. I may be audio taped during class activities or after class if an informal interview is needed.

I understand that risks associated with this study are minimal. I understand that I may decline to participate in any aspect of the study that I may not feel comfortable with doing. I will not receive any benefits or monetary compensation for my participation in this study.

This study is confidential. The records of this study will be kept private. No identifiers linking me to the study will be included in any sort of report that might be published. Research records will be stored securely and only the principal investigator, Sally Gerren, and her committee members, Dr. Gerald Kulm and Dr. Carol Stuessy, will have access to the records and tapes. Tape recordings will be erased one year after the study is completed.

My decision whether or not to participate will not affect any current or future relations with Texas A&M University or Navarro College South Campus. If I decide to participate, I am free to refuse to answer any of the questions that may make me uncomfortable. I can withdraw at any time without my relations with the university or college being affected. I can contact the following individuals to ask questions about this study: the principal investigator, Sally Gerren, at (254) 472-0579, 3554 LCR 486, Mexia, Texas 76667, sally-sue-gerren@tamu.edu, her advisors at Texas A&M University, Department of Teaching, Learning, and Culture, Mail Stop 4232, College Station, Texas 77843, Dr. Gerald Kulm, at (979) 862-4407 or gkulm@tamu.edu, and Dr. Carol Stuessy, at (979) 862-8374 or c-stuessy@tamu.edu, with any questions about this study.

Teacher Consent Form Continued

This research study has been reviewed by the Institutional Review Board- Human Subjects in Research, Texas A&M University. For research-related problems or questions regarding subjects' rights, I can contact the Institutional Review Board through Ms. Angelia M. Raines, Director of Research Compliance, at (979) 458-4067 or araines@vprmail.tamu.edu. I have read the above information. I have asked questions and have received answers to my satisfaction. I have been given a copy of this consent document for my records. By signing this document, I consent to participate in the study.

Signature: ____ Date: ___________________

Signature of Investigator: __________________________________ Date: ___________________

Student Consent Form

STUDENT CONSENT FORM

A CASE STUDY: THE RELATIONSHIP BETWEEN THE USE OF GRAPHING CALCULATORS AND THE DEVELOPMENT OF CLASSROOM NORMS IN A COLLEGE ALGEBRA COURSE

I have been asked to participate in a research study for the purpose of exploring the relationship between the use of graphing calculators by members of a college algebra class and the classroom norms that develop that give meaning and purpose to the instrument's use. This study is intended to fulfill the dissertation requirement for completion of the PhD degree program for the principal investigator, Sally Gerren. I was selected to be a possible participant because I am enrolled as a student in the college algebra class that was chosen for the inquiry. A total of twenty to thirty people have been asked to participate in this study.

If I agree to be in this study, I will be asked to complete a short questionnaire each class session, allow the investigator to observe class activities, and participate in informal interviews as needed to clarify information about an observation or a questionnaire. My classroom participation and/or interviews may be audio taped to preserve accuracy in the collection of data. I will be informed when audio taping is to occur. This study will be conducted throughout the course's duration, approximately 14 weeks. I will be asked to complete an initial questionnaire and then either a lesson or assessment questionnaire each class period afterward during the course. I may be audio taped during class activities or after class if an informal interview is needed.

I understand that risks associated with this study are minimal. I understand that I may decline to participate in any aspect of the study that I may not feel comfortable with doing. I will not receive any benefits, monetary compensation, or class points for my participation in this study.

This study is confidential. The records of this study will be kept private. No identifiers linking me to the study will be included in any sort of report that might be published. Research records will be stored securely and only the principal investigator, Sally Gerren, and her committee members, Dr. Gerald Kulm and Dr. Carol Stuessy, will have access to the records and tapes. Tape recordings will be erased one year after the study is completed.

My decision whether or not to participate will not affect my grade in this class or any other current or future relations with Texas A&M University or Navarro College South Campus. If I decide to participate, I am free to refuse to answer any of the questions that may make me uncomfortable. I can withdraw at any time without my relations with the university, college, or class being affected. I can contact the following individuals to ask questions about this study: the principal investigator, Sally Gerren, at (254) 472-0579, 3554 LCR 486, Mexia, Texas 76667, sally-sue-gerren@tamu.edu; her advisors at Texas A&M University, Department of Teaching, Learning, and Culture, Mail Stop 4232, College Station, Texas 77843, Dr. Gerald Kulm, at (979) 862-4407 or gkulm@tamu.edu, and Dr. Carol Stuessy, at (979) 862-8374 or c-stuessy@tamu.edu, with any questions about this study.

Student Consent Form Continued

This research study has been reviewed by the Institutional Review Board- Human Subjects in Research, Texas A&M University. For research-related problems or questions regarding subjects' rights, I can contact the Institutional Review Board through Ms. Angelia M. Raines, Director of Research Compliance at (979) 458-4076 or araines@vprmail.tamu.edu. I have read the above information. I have asked questions and have received answers to my satisfaction. I have been given a copy of this consent document for my records. By signing this document, I consent to participate in the study.

Signature: ______________________________________ Date: ________________

Signature of Investigator: ____________________________ Date: ________________

APPENDIX D

AUDIT TRAIL

AUDIT TRAIL

This Audit Trail outlines the data collection process conducted in the spring of 2005 at a northeast Texas community college to identify relationships that may exist between graphing calculator use and classroom norms in a college algebra class. Data includes (1) informal interviews with the instructor and students of the college algebra class (2) documents and records collected to provide information pertinent to the study (3) observations of all 29 class sessions (4) M-SCOPE data of the 23 lesson sessions (5) questionnaires regarding teacher lesson plans and students' background, lesson, and assessment information.

Explanation of Codes

Each item is designated with a three digit code. The first digit of the code represents the source of data. Codes and sources of data include the following: I-interview, F-field notes, Q-questionnaire, M-M-SCOPS, and D-document. The second digit identifies the specific type of source data and includes the following: T-teacher, S-student, L-lesson sessions, B-test sessions, I-initial student background, L-student lesson questionnaire, A-student assessment questionnaire, T-teacher lesson plans; M-SCOPS, V-visual profile; documents, C-course syllabus, G-graphing calculator handouts, R-lesson resource, Q-quiz, T-test, W-student work; records, G-student grades, E-teacher evaluation. The third digit indicates the number of the specific data source.

ITEM	CODE	SOURCE	DATE
1	I-T-1	Interview with Mrs. A	8-1-05
2	I-T-2	Interview with Mrs. A	12-5-05
3	F-L-1	Field Notes for Class 1	1-18-06
4	Q-I-1	Students' Initial Background Questionnaires	1-18-06
5	Q-L-1	Students' Lesson Questionnaire	1-18-06
6	Q-T-1	Teacher Lesson Plan Questionnaire	1-17-06
7	M-V-1	M-SCOPS Visual Profile	1-18-06
8	D-C-1	Course Syllabus	1-18-06
9	D-G-1	TI 83 Menu Map	1-18-06
10	D-G-2	Graphing Calculator Instructional Guide: Getting Started on the TI 83-Graphing, Tables, and More!	1-18-06
11	D-R-1	Study Guide for Chapter One	1-18-06
12	F-L-2	Field Notes for Class 2	1-23-06
13	Q-L-2	Students' Lesson Questionnaires	1-23-06
14	Q-T-2	Teacher Lesson Plan Questionnaire	1-23-06
15	M-V-2	M-SCOPS Visual Profile	1-23-06
16	I-S-1	Interview with Student Code 6	1-23-06
17	I-T-3	Interview with Mrs. A	1-23-06
18	F-L-3	Field Notes for Class 3	1-25-06
19	Q-L-3	Students' Lesson Questionnaires	1-25-06
20	Q-T-3	Teacher Lesson Plan Questionnaire	1-25-06
21	M-V-3	M-SCOPS Visual Profile	1-25-06
22	D-R-2	Study Guide for Chapter 2	1-25-06
23	D-G-3	Graphing Calculator Instructional Guide: Plotting Scatter Plots and Formulating Regression Equations	1-25-06
24	D-R-3	Practice Test for Chapters 1 and 2	1-25-06
25	F-L-4	Field Notes for Class 4	1-30-06
26	Q-L-4	Students' Lesson Questionnaires	1-30-06
27	Q-T-4	Teacher Lesson Plan Questionnaire	1-30-06
28	M-V-4	M-SCOPS Visual Profile	1-30-06
29	F-L-5	Field Notes for Class 5	2-1-06
30	Q-L-5	Students' Lesson Questionnaires	2-1-06
31	M-V-5	M-SCOPS Visual Profile	2-1-06
32	I-S-2	Interview with Student Code 6	2-1-06
33	F-L-1	Field Notes for Class 6	2-6-06
34	Q-A-1	Students' Assessment Questionnaires	2-6-06
35	Q-T-5	Teacher Lesson Plan Questionnaire	2-6-06
36	D-B-1	Test 1: Chapters 1 and 2	2-6-06
37	D-Q-1	Quiz: Scatter Plots and Data Analysis	2-6-06
38	D-R-4	Vocabulary Sheet	2-6-06
39	D-R-5	Worksheet on Functional Concepts	2-6-06

Audit Trail Continued

ITEM	CODE	SOURCE	DATE
40	D-R-6	Study Guide for Chapters 3 and 4	2-6-06
41	D-R-7	Practice Test for Chapters 3 and 4	2-6-06
42	F-L-6	Field Notes for Class 7	2-8-06
43	Q-L-6	Students' Lesson Questionnaires	2-8-06
44	M-V-6	M-SCOPS Visual Profile	2-8-06
45	F-L-7	Field Notes for Class 8	2-13-06
46	Q-L-7	Students' Lesson Questionnaires	2-13-06
47	M-V-7	M-SCOPS Visual Profile	2-13-06
48	F-L-8	Field Notes for Class 9	2-15-06
49	Q-L-8	Students' Lesson Questionnaires	2-15-06
50	M-V-8	M-SCOPS Visual Profile	2-15-06
51	F-L-9	Field Notes for Class 10	2-20-06
52	Q-L-9	Students' Lesson Questionnaires	2-20-06
53	Q-T-6	Teacher Lesson Plan Questionnaire	2-20-06
54	M-V-6	M-SCOPS Visual Profile	2-20-06
55	D-Q-2	Quiz: Library of Functions	2-20-06
56	D-R-8	Study Sheet for Transformations and Piece-Wise Defined Functions	
57	F-L-10	Field Notes for Class 11	2-22-06
58	Q-L-10	Students' Lesson Questionnaires	2-22-06
59	M-V-10	M-SCOPS Visual Profile	2-22-06
60	I-T-4	Interview with Mrs. A	2-22-06
61	F-L-11	Field Notes for Class 12	2-27-06
62	Q-L-11	Students' Lesson Questionnaires	2-27-06
63	Q-T-7	Teacher Lesson Plan Questionnaire	2-27-06
64	M-V-11	M-SCOPS Visual Profile	2-27-06
65	D-Q-3	Quiz: Transformations and Reflections	2-27-06
66	F-L-12	Field Notes for Class 13	3-1-06
67	Q-L-12	Students' Lesson Questionnaires	3-1-06
68	M-V-12	M-SCOPS Visual Profile	3-1-06
69	I-T-5	Interview with Mrs. A	3-1-06
70	R-A-1	Students' E-Mail Responses	3-1-06
71	F-I-2	Field Notes for Class 14	3-6-06
72	Q-I-2	Students' Assessment Questionnaires	3-6-06
73	D-B-2	Test 2: Chapters 3 and 4	3-6-06
74	D-R-9	Chapter Five Homework Problems and Practice Test	3-6-06
75	F-L-13	Field Notes for Class 15	3-20-06
76	Q-L-13	Students' Lesson Questionnaires	3-20-06
77	M-V-13	M-SCOPS Visual Profile	3-20-06

Audit Trail Continued

ITEM	CODE	SOURCE	DATE
78	Q-T-8	Teacher Lesson Plan Questionnaire	3-20-06
79	I-S-3	Interview with Student Code 6	3-20-06
80	F-L-14	Field Notes for Class 16	3-22-06
81	Q-L-14	Students’ Lesson Questionnaires	3-22-06
82	M-V-14	M-SCOPS Visual Profile	3-22-06
83	Q-T-9	Teacher Lesson Plan Questionnaire	3-22-06
84	F-L-15	Field Notes for Class 17	3-27-06
85	Q-L-15	Students’ Lesson Questionnaires	3-27-06
86	M-V-15	M-SCOPS Visual Profile	3-27-06
87	Q-T-10	Teacher Lesson Plan Questionnaire	3-27-06
88	F-L-16	Field Notes for Class 18	3-29-06
89	Q-L-16	Students’ Lesson Questionnaires	3-29-06
90	M-V-16	M-SCOPS Visual Profile	3-29-06
91	Q-T-11	Teacher Lesson Plan Questionnaire	3-29-06
92	D-Q-3	Quiz: Chapter 5	3-29-06
93	F-L-17	Field Notes for Class 19	4-3-06
94	Q-L-17	Students’ Lesson Questionnaires	4-3-06
95	M-V-17	M-SCOPS Visual Profile	4-3-06
96	Q-T-12	Teacher Lesson Plan Questionnaire	4-3-06
97	F-A-3	Field Notes for Class 20	4-5-06
98	Q-A-3	Students’ Assessment Questionnaires	4-5-06
99	Q-T-13	Teacher Lesson Plan Questionnaire	4-5-06
100	D-B-3	Test: Chapter 5	4-5-06
101	D-R-10	Matrix Concept Summary & Homework Problems	4-5-06
102	D-R-11	Study Guide for Conic Sections	4-5-06
103	D-R-12	Practice Test Questions for Conics and Matrices	4-5-06
104	F-L-18	Field Notes for Class 21	4-10-06
105	Q-L-18	Students’ Lesson Questionnaires	4-10-06
106	M-V-18	M-SCOPS Visual Profile	4-10-06
107	Q-T-14	Teacher Lesson Plan Questionnaire	4-10-06
108	F-L-19	Field Notes for Class 22	4-11-06
109	Q-L-19	Students’ Lesson Questionnaires	4-11-06
110	M-V-19	M-SCOPS Visual Profile	4-11-06
111	Q-T-15	Teacher Lesson Plan Questionnaire	4-12-06
112	F-L-20	Field Notes for Class 23	4-17-06
113	Q-L-20	Students’ Lesson Questionnaires	4-17-06
114	M-V-20	M-SCOPS Visual Profile	4-17-06
115	Q-T-16	Teacher Lesson Plan Questionnaire	4-17-06
116	D-Q-5	Quiz: Matrix	4-17-06
117	D-R-13	Study Guide for Patterns, Sequences, and Series	4-17-06

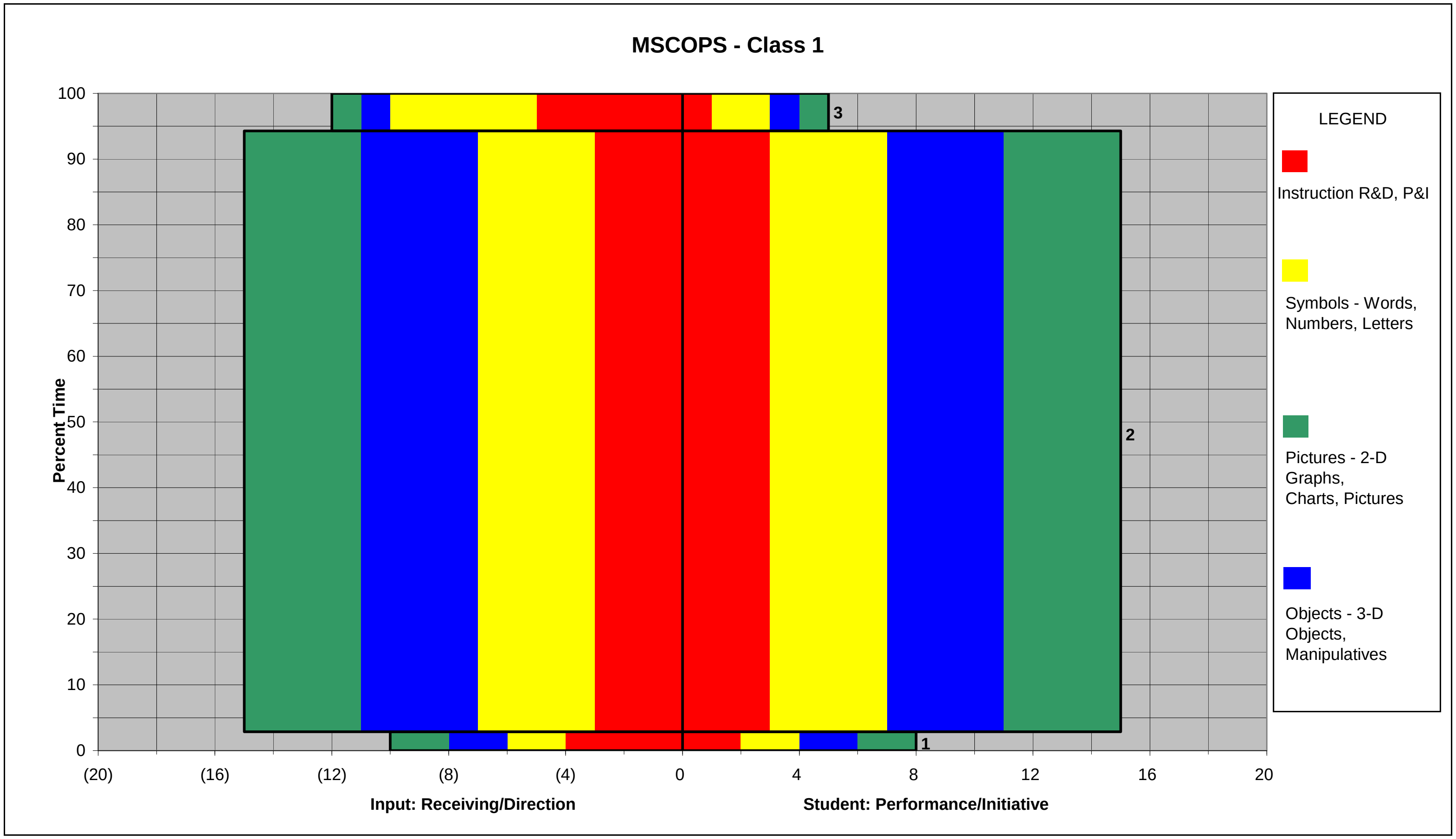
Audit Trail Continued

ITEM	CODE	SOURCE	DATE
118	D-R-14	Practice Test Questions for Sequences	4-17-06
119	I-T-6	Interview with Mrs. A	4-17-06
120	F-L-21	Field Notes for Class 24	4-19-06
121	Q-L-21	Students' Lesson Questionnaires	4-19-06
122	M-V-21	M-SCOPS Visual Profile	4-19-06
123	Q-T-17	Teacher Lesson Plan Questionnaire	4-19-06
124	F-L-22	Field Notes for Class 25	4-24-06
125	Q-L-22	Students' Lesson Questionnaires	4-24-06
126	M-V-22	M-SCOPS Visual Profile	4-24-06
127	Q-T-18	Teacher Lesson Plan Questionnaire	4-24-06
128	D-Q-6	Quiz: Conics	4-24-06
129	F-L-23	Field Notes for Class 26	4-26-06
130	Q-L-23	Students' Lesson Questionnaires	4-26-06
131	M-V-23	M-SCOPS Visual Profile	4-26-06
132	Q-T-19	Teacher Lesson Plan Questionnaire	4-26-06
133	I-S-4	Interview with Student Code 6	4-26-06
134	F-A-4	Field Notes for Class 27	5-1-06
135	Q-A-4	Students' Assessment Questionnaires	5-1-06
136	D-B-4	Test 4: Chapters 6-8	5-1-06
137	I-S-5	Interview with Student Code 6	5-1-06
138	I-S-6	Interview with Student Code 3	5-3-06
139	I-S-7	Interview with Student Code 5	5-3-06
140	F-L-24	Field Notes for Class 28	5-3-06
141	Q-L-24	Student Lesson Questionnaire	5-3-06
142	I-S-8	Interview with Student Code 8	5-3-06
143	F-A-5	Field Notes for Class 29	5-8-06
144	Q-A-5	Student Assessment Questionnaire	5-8-06
145	D-B-5	Final Exam	5-8-06
146	I-T-7	Interview with Mrs. A	5-8-06
147	D-G-1	Students' Grades	6-1-06
148	D-E-1	Teacher Evaluation	6-1-06
149	D-E-2	Students' Course Evaluations	8-5-06

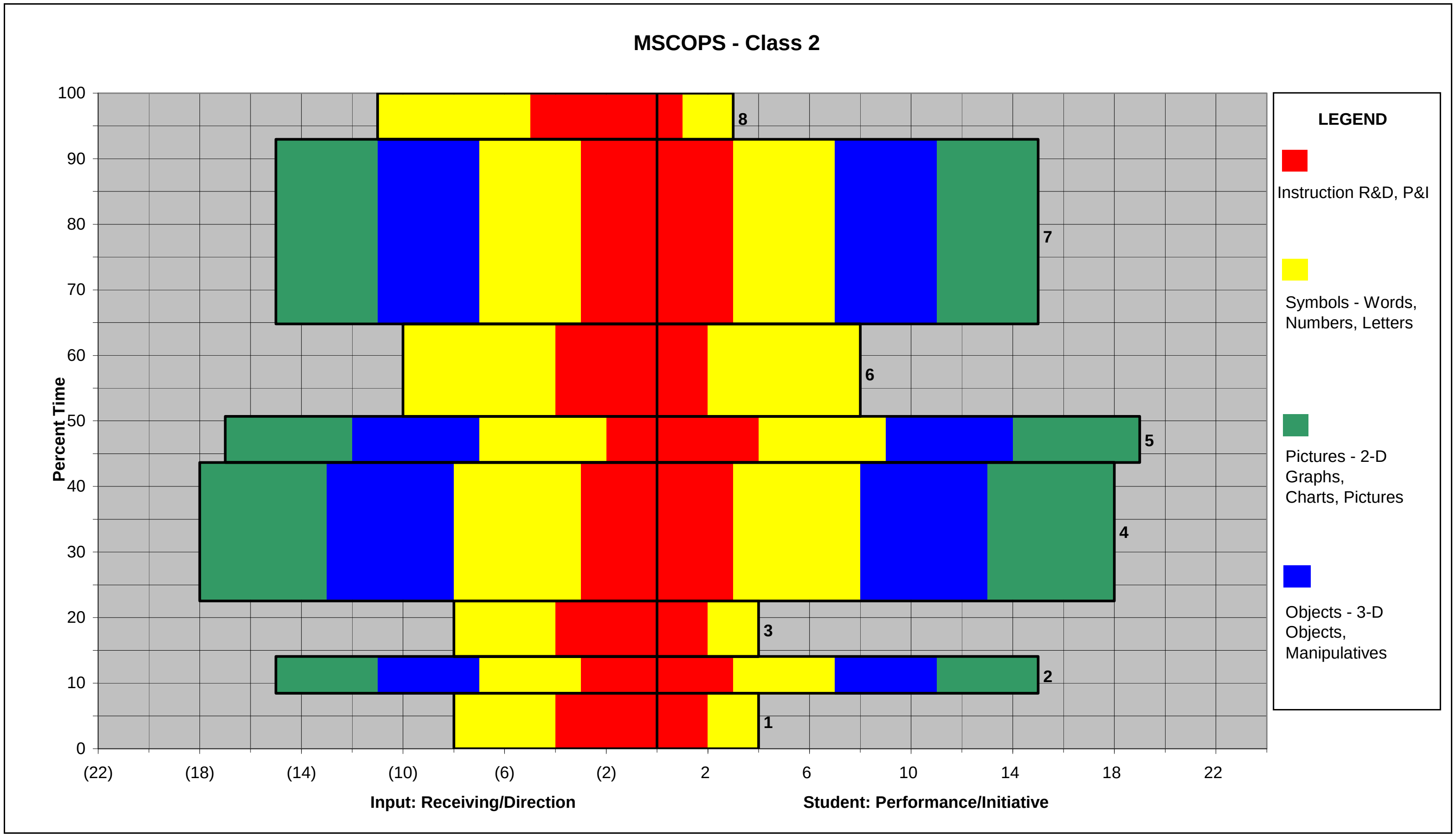
APPENDIX E

M-SCOPS PROFILES

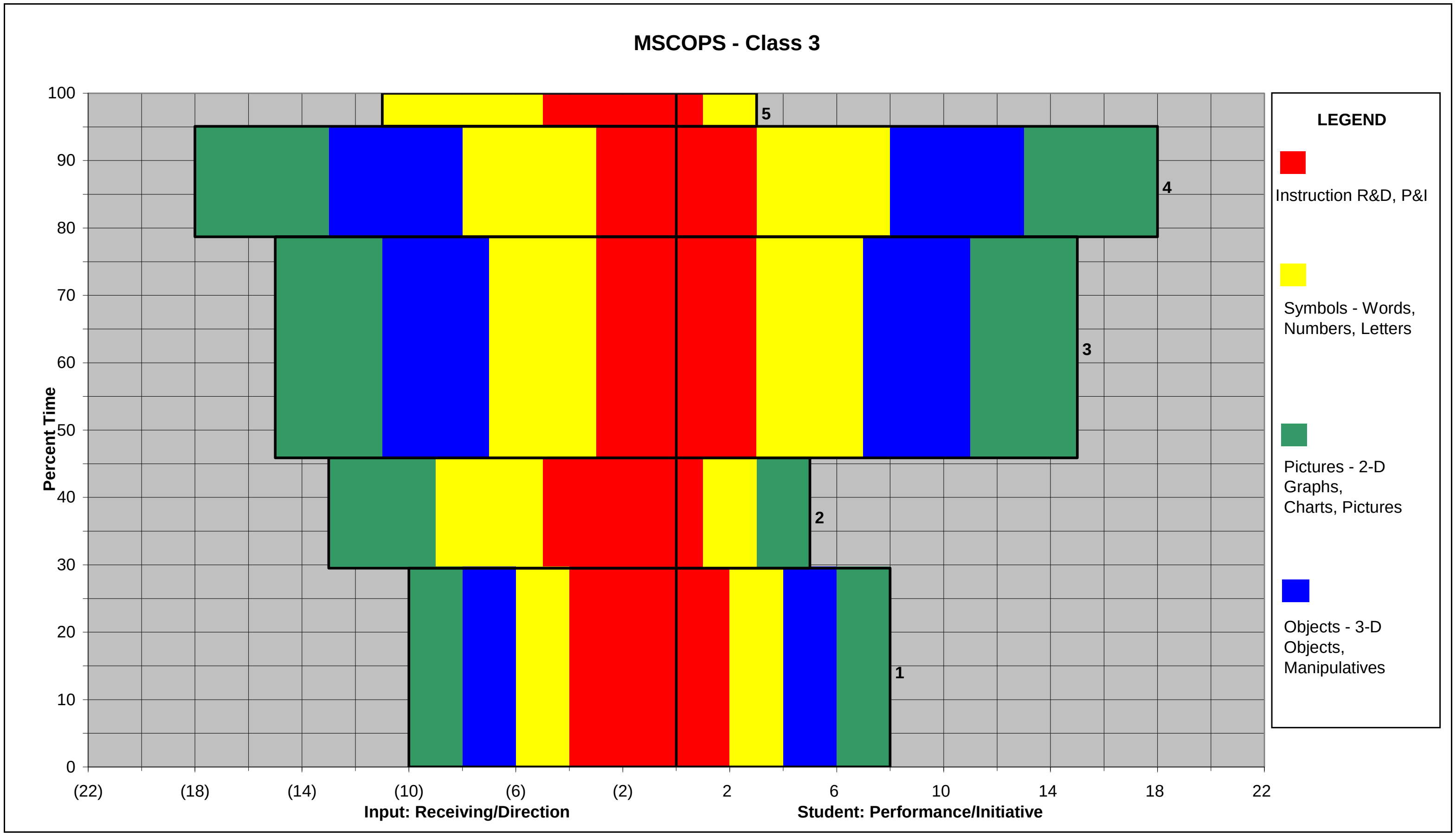
M-SCOPS Profile: Class 1



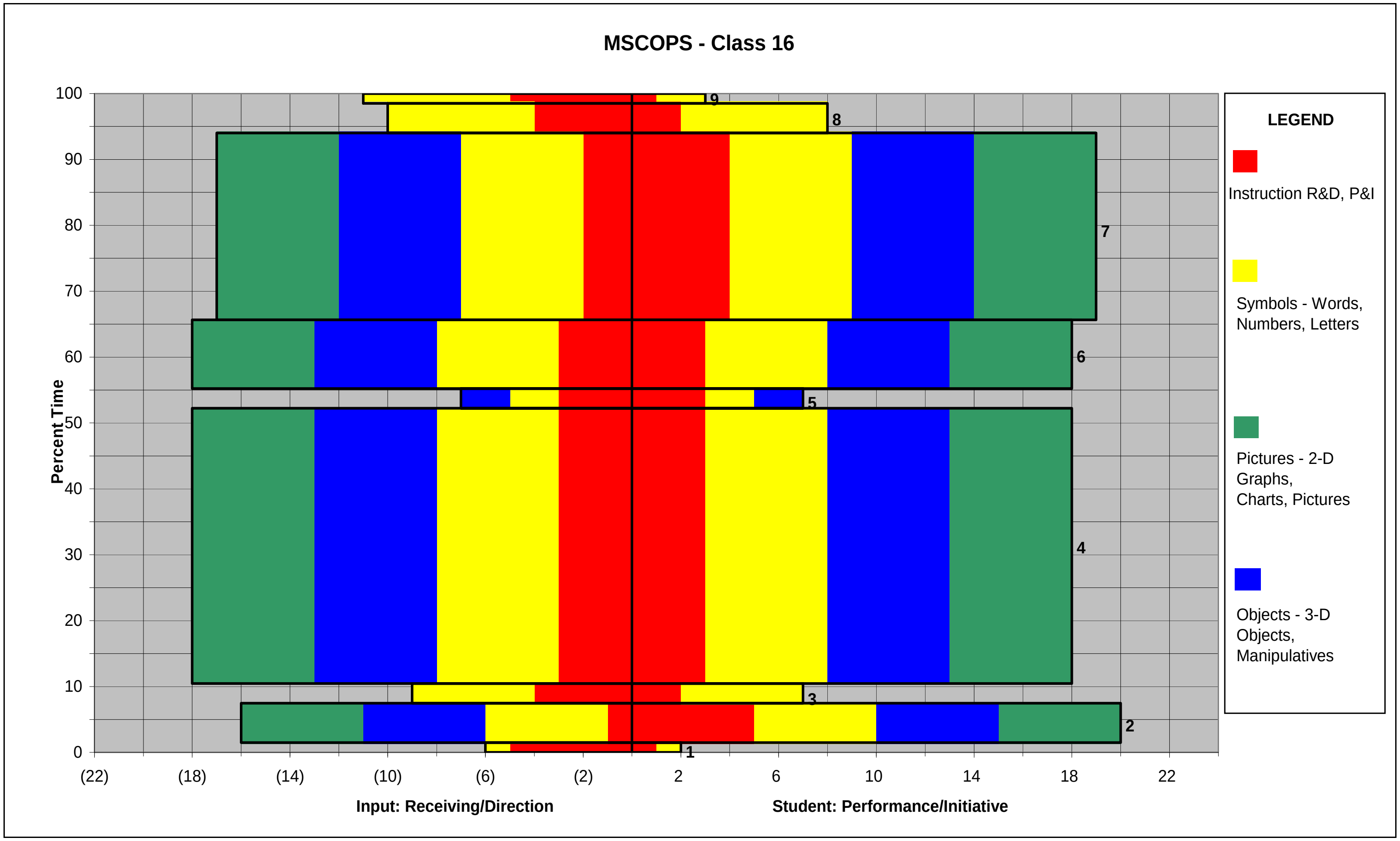
M-SCOPS Profile: Class 2



M-SCOPS Profile: Class 3



M-SCOPS Profile: Class 16



VITA

Name:	Sally Sue Gerren
Address:	Mexia High School 1120 North Ross Street Mexia, TX 76667
Email Address:	sgerren@earthlink.net

Education:	B.S., Interdisciplinary Studies, Texas A&M University, 1993 M.Ed., Curriculum & Instruction, Texas A&M University, 1999 Ph.D., Curriculum & Instruction, Texas A&M University, 2008