TERESA GAIL BANKER
Preservice Secondary Mathematics Teachers' Beliefs and Practice Regarding the Use of Graphing Calculators in Mathematics Instruction
(Under the Direction of DENISE S. MEWBORN)

This study investigated preservice teachers' decisions about use of the graphing calculator during instruction. Particularly, the study noted how the graphing calculator was used in instruction, why the preservice teachers chose to use or chose not to use the graphing calculator, what they found problematic about the use of the calculator, and with which mathematics they used the graphing calculator. Data were collected in the form of classroom observations, e-mail responses, individual interviews, and essays. Data were analyzed using the methods of grounded theory (Creswell, 1998; Merriam, 1998).

Two preservice secondary mathematics teachers completed student teaching in the spring of 2001. They were involved in all the duties and activities pursuant to the role of a high school mathematics teacher—planning, teaching, and assessing lessons for their course curricula; working with individual students; and designing projects for their classes. During student teaching, they also used the graphing calculator for mathematics instruction.

The preservice teachers' ways of using the graphing calculator were analyzed in terms of Elaine Simmt's (1997) categories of use from her study about graphing calculators. The preservice teachers' categories of use aligned with the ones that Simmt identified. These categories revealed *how* the preservice teachers used the graphing calculator. The categories of use found for the two preservice teachers in this study were as a tool for 1) checking work, 2) finding graphical solutions, 3) exploring deeper, richer mathematics, 4) generating alternate solutions, 5) simulating real-world phenomena, 6) visualization, and 7) motivation.

Another focus of the study was what the preservice teachers found problematic when using graphing calculators in the mathematics classroom. The preservice teachers reported that problematic issues centered on time and materials for planning, on finding a balance in the appropriate amount of use, and on student resistance.

Understanding *when* the graphing calculators were used forced a review of the mathematics with which the preservice teachers worked. Two content areas were dominant: computation (i.e., arithmetic operations, statistical, probabilistic, evaluative, and trigonometric) and algebra (i.e., solving one-and-two step equations and inequalities, lines—including linear regression problems, and creating T-tables).

INDEX WORDS: Preservice Teachers, Graphing Calculator, Secondary Mathematics, Teacher Beliefs

PRESERVICE SECONDARY MATHEMATICS TEACHERS' BELIEFS AND PRACTICE REGARDING THE USE OF GRAPHING CALCULATORS IN MATHEMATICS INSTRUCTION

by

TERESA GAIL BANKER

B. S., Old Dominion University, 1970

M. Ed., North Georgia College, 1983

Ed. S., University of Georgia, 1997

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TERESA GAIL BANKER

Approved:

Major Professor: Denise S. Mewborn

Committee: Thomas J. Cooney
Paul R. Wenston
James W. Wilson
Patricia S. Wilson

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
December 2001

DEDICATION

To my parents,

Charles and Jo Shinlever,

for their constant support and encouragement.

Two roads diverged in a wood, and I—
I took the one less traveled by,
And that has made all the difference.

Robert Frost

"The Road Not Taken"

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CHAPTER 1

THE PROBLEM AND ITS BACKGROUND

This is the account of my efforts to understand *how, when,* and *why* preservice secondary mathematics teachers use the graphing calculator in mathematics instruction during student teaching. To understand the *how* and *when* of graphing calculator use, I decided that examination of the *practice* of these preservice teachers was necessary. *Teaching practice* is generally considered the teaching actions of a teacher, affected by her philosophies regarding mathematics and mathematics education. The examination of philosophies is the *why*, (i.e., looking at a teacher's beliefs about mathematics and about mathematics education).

This is also the account of two young women who agreed to work with me as I sought to understand the factors that influence graphing calculator use. Both young women were most gracious with their time, and both shared their experiences with the graphing calculator during student teaching, the capstone field experience in their teacher education programs.

In the last fifteen years, it has become common practice to incorporate the graphing calculator into the curriculum of Algebra II in high school; in both high school and college, the same has been done in Pre-calculus and Calculus courses. In Algebra I classes that I taught in the spring of 1997, I engaged in action research; the study was based on my belief that Algebra I students would benefit from the use of a graphing calculator. These classes were predominately composed of ninth graders.

The results from my study indicated that more than half of my students worked harder at symbolic manipulative skills in order to get the calculator to work for them. When working with the graphing calculator, it is necessary to solve linear equations in x and y for the y variable, (i.e., in the form $y =$). Students who were previously easily frustrated by symbolic manipulation worked to obtain the correct expression needed for the calculator syntax because the correct expression produced the expected graph. Thus, the graphing calculator motivated students to persist in producing better quality work (Mesa, 1997). In addition, assessment scores for the topics in which students were allowed to use graphing calculators appeared to be higher than in previous years.[1]

Although other Algebra I teachers chose not to use graphing calculators with their students, my action research confirmed some benefits of calculator use for my Algebra I students. The difference in practice regarding the use of graphing calculators with this level student developed from, I think, beliefs about student abilities and the mathematics those students are able to do. My belief that Algebra I students had the ability to use the graphing calculator productively was the driving force (Thompson, 1984) of the action research.

In light of that limited study, I wanted to investigate the beliefs and philosophies of preservice teachers about using the graphing calculator in mathematics instruction. I chose this topic because of previous research done with inservice mathematics teachers. For example, Simmt (1997) found that inservice teachers used graphing calculators to enhance the teachers' usual method of teaching. "No new methods or approaches…were used by the teacher"(p. 287). Simmt called for research with preservice and inservice teachers to identify and

[1] I say "appeared to be higher" because I could not access previous years' records to make comparisons. This assertion is based on my experiences teaching Algebra I for many years.

address issues related to personal philosophies about mathematics and about mathematics education because her study suggested, "one's philosophy of mathematics is manifested in one's instruction of mathematics" (p. 287).

In my study, I hoped to describe and better define the factors that influence how and when preservice secondary mathematics teachers use the graphing calculator in mathematics instruction during student teaching. I was interested in how the preservice teachers' beliefs and philosophies about students, about mathematics, about teaching, and about learning influence their views about the use of graphing calculators.

Background

The National Council of Teachers of Mathematics in the *Curriculum and Evaluation Standards* (NCTM, 1989) recommended the use of calculators in all grade levels:

> For Grades K-4, integrating calculators and computers into school mathematics programs is critical in meeting the goals of a redefined curriculum. (p. 19)
>
> For Grades 5-8, all students will have a calculator with functions consistent with the tasks envisioned in this curriculum. (p. 19)
>
> For Grades 9-12, scientific calculators with graphing capabilities will be available to all students at all times. (p. 124)

The vision reflected in these position statements is that the appropriate use of calculators at all levels enhances the teaching and learning of mathematics and, ultimately, changes *how* mathematics is taught and learned. These changes in *how* mathematics is taught and learned also precipitate changes in *what* mathematics is learned:

> With technology at hand, young children can explore and solve problems involving large numbers…Elementary school students can organize and analyze large sets of data. Middle–grades students can study linear relationships and the ideas of slope and uniform change with computer representations and by performing physical experiments with calculator-based-laboratory systems. High school students can use simulations to study sample distributions, and they can work with computer algebra systems that efficiently perform most of the symbolic manipulation that was the focus of traditional high school mathematics programs. The study of algebra need not be limited to simple situations…Using technological tools, students can reason about more general issues…and they can model and solve complex problems that were heretofore richer to them. (NCTM, 2000, p. 26)

The importance of using calculator technology, as well as other technologies such as computer software that graphs functions, seems readily evident. Many research studies support these claims about the benefits of technology use, especially calculator technology.

Researchers report that young children benefit from calculator use, that they develop number sense, and that "there was no evidence that children became reliant on calculators at the expense of their ability to use other methods of computation" (Groves & Stacey, 1998, p. 128). The *Standards* view that calculator technology should play a role in mathematics instruction is supported by empirical evidence from research (Heid, 1997; Dunham & Dick, 1994; Hembree & Dessart, 1986, 1992). Empirical evidence also supports graphing calculator use in mathematics instruction (e.g., for increasing understanding of mathematics concepts, for increasing confidence with mathematics, and for increasing the performance levels of special groups) (Austin, 1997; Bitter & Hatfield, 1993; Demana, Schoen, & Waits, 1993; Dick, 1992; Dunham & Dick, 1994; Galindo-Morales, 1995; Heid, 1997; Hembree & Dessart, 1986,1992; Keller & Russell, 1997; Mesa, 1997; Ruthven, 1990; Siskind, 1995; Slavit, 1994).

Statement of the Problem

In spite of all the research that documents its benefits, graphing calculator technology has had very little impact on mathematics instruction. Some would say administrators have failed to provide funding to purchase calculators, but the relatively low cost of graphing calculators makes the technology accessible to many school systems and individual students as well (Wilson & Krapfl, 1994). As Dunham (2000) noted, “The cost of a single computer could supply several classrooms with a set of calculators” (p. 43). Rather than financial reasons then, I think it is teachers’ beliefs about mathematics and about mathematics instruction that has kept graphing calculator technology from impacting mathematics instruction in a larger way. As Kilpatrick (1994) put it:

> Researchers in mathematics education have yet to examine how the availability of computer technology might interact with teachers’ beliefs and capabilities as well as with institutional and social constraints on the improvement of mathematics instruction. (p. 3649)

Some research has concluded that teacher beliefs about mathematics and about mathematics instruction actually interfere with the use of the graphing calculator in mathematics instruction (Drier, 1998; Dunham & Dick, 1994; Fleener, 1995; Haimes, 1996; Ruthven, 1990; Simmt, 1997; Strudler, 1993; Tharp, et al., 1997; Wilson & Krapfl, 1994)[2]. Some beliefs that interfere with the use of the graphing calculator are teachers’ fears that students will not develop good basic skills, that students will use calculators as crutches, and that students will not master basic concepts.

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[2] Graphing calculators are considered computer technology because the calculators are hand-held computers.

Studies show that inservice teachers are reluctant to fully integrate graphing calculators into mathematics instruction (Drier, 1998; Fleener, 1995; Jost, 1992; May, 1994; Simmt, 1997; Tharp, Fitzsimmons & Brown Ayers, 1997), but not much is known about the beliefs of preservice secondary mathematics teachers and the implementation of the graphing calculator (Simmt, 1997). Some major factors of influence appear to affect teachers' decisions about *how* and *when* to use the graphing calculator in mathematics instruction. These factors include the individual's recognition of advantages of use of graphing calculators (Bialo & Erickson, 1985; Ruthven, 1990), the individual's position on concept mastery[3] (Fleener, 1995), whether the individual views mathematics instruction as rule-based or non-rule-based (Tharp, et al., 1997), and the individual's preconceived images about mathematics instruction (Brown & Borko, 1992; Brown, Cooney, & Jones, 1990; Haimes, 1996; Thompson, 1985)[4]. Getting more information about these factors of influence can help us understand their role in teachers' decisions about implementation of the graphing calculator into mathematics instruction.

Rationale

According to Bright and Williams (1994), the mathematics education community could use more research that attempts to explain the relationships between factors of influence and graphing calculator use. Studies are needed that document *how* and *when* teachers decide to use the calculators and on what kinds

[3] The issue of concept mastery is based on the teacher's belief that students should know and understand the concept before the introduction of the calculator. This belief usually precludes the calculator as a concept-development tool.

[4] Although these researchers do not specifically mention the graphing calculator, the point of their discussions focused on how teachers' beliefs impact teaching practice, which I think is a major influence in how and when graphing calculators are used in instruction.

of tasks. Dunham and Dick (1994) stated that research evidence exists that supports the use of graphing calculators in mathematics instruction, but more knowledge is required about "the attitudes of both teachers and students toward the technology" (p. 444).

As these relationships between factors of influence and graphing calculator use are further defined, mathematics educators can gain understanding about the types of knowledge necessary for teachers to use graphing calculators. Appropriate professional development opportunities can be provided for both inservice and preservice teachers. Preservice teachers, in particular, need to learn about calculator research and calculator methods during their course of study. Mathematics educators need to provide for preservice teachers information about and experiences with calculator-enhanced instruction.

I designed this study to investigate preservice teachers' use of a graphing calculator during student teaching in an attempt to understand the decisions preservice secondary mathematics teachers make about how and when to use graphing calculators in mathematics instruction. The research questions guiding the study were:

1. What do preservice secondary mathematics teachers find problematic about the use of graphing calculators in mathematics instruction?

2. What factors influence the use of graphing calculators in mathematics instruction?

3. When do preservice secondary mathematics teachers use graphing calculators in instruction during student teaching? If they do not use graphing calculators, do they make a deliberate choice not to do so? If so, what are the reasons for those choices? If the choice is not deliberate, what factors is the student teacher considering when planning instruction?

As suggested by Thompson (1992), the study of "teachers' beliefs is fundamentally problematic" (p. 134). Thompson stated that examining teachers' verbal data alone is not enough, and that this examination should be supplemented with "observational data of instructional practice or mathematical behavior" (p. 135). The design for this study was formulated with Thompson's guidelines for such studies, including verbal data, "observational data of instructional practice," and "mathematical behavior" when using graphing calculators.

CHAPTER 2

REVIEW OF RELEVANT LITERATURE

Three bodies of literature were reviewed to form a foundation for this study on graphing calculator use. Literature on graphing calculators formed the major building block because that is the main focus of the study. My own action research confirmed some of the research in this review. Tied to the graphing calculator research is the role of graphing calculators in the reform of school mathematics because the graphing calculator is a tool of reform. Literature on beliefs formed a basis for examining the preservice teachers' beliefs about mathematics and mathematics education and the relationship of those beliefs to practice. The literature on graphing calculators aided analysis of *how* graphing calculators were used in mathematics instruction.

Graphing Calculators

The graphing calculator was first introduced in 1986 by Casio. The former methods of expository teaching and pencil-and-paper manipulations were challenged by the technology because new methods were possible. Mathematics educators were then faced with striking a balance between the new graphing calculator technology and pencil-and-paper manipulations because the graphing calculator provided a convenient tool for computation, but this tool needed to be used appropriately. Thus, mathematics content would change.

History is a good indicator of some changes that will come to mathematics. Examine the earlier advent of the scientific calculator and what mathematics content was altered. Some of the mathematics taught from 1961 to 1976 became obsolete (Herrera, 2001) "because the scientific calculator was a better tool—a better way to compute" (p. 27). For example, the teaching of logarithms required common logarithmic tables formulated on base 10 because our number system uses base 10 (Foster, Rath, & Winters, 1986). The values in the tables were called mantissas, and the tables contained mantissas for numbers between 1 and 10. The *mantissa* is the log of the number to base 10. Scientific notation determined the *characteristic* of the number; the characteristic was related to the magnitude of the number. From these tables the mantissa of the number is found, and operations on numbers using multiplication or division became addition or subtraction, respectively, following the rules for exponents. The scientific calculator had these tables built into its functions and relieved the tedium of using the tables. However, using the scientific calculator for logarithms still required students to manipulate correctly the rules for exponents.

Many teachers fear that the graphing calculator erases the need for pencil-and-paper manipulations, but this fear is unfounded. For example, students in middle grades and high school need to have many experiences plotting points on graph paper and connecting those points to drive home an understanding of that process—all of these manipulations *before* the graphing calculator is introduced for student use (Herrera, 2001). Other fears of teachers and parents stem from concerns that students will lose computational skills, that students will use calculators as crutches, and that students will not master basic concepts (Fleener, 1995; Simonsen & Dick, 1997; Zand & Crowe, 1997). Unfortunately, parents and teachers are often unaware of research that supports the benefits of calculator-based instruction (Fine & Fleener, 1994).

Students in courses such as algebra, trigonometry, calculus, and statistics registered positive benefits with the use of graphing calculators. Research reviews by Dunham (1995), Dunham and Dick (1994), Heid (1997), and Penglase and Arnold (1996) all agree that students using graphing calculators have increased achievement scores on tests of algebra and calculus, have stronger understandings of function and graph concepts, and have improved problem solving skills. Other studies show that special groups have been helped by the graphing calculator: women (Dunham, 1995; Smith & Shotsberger, 1997), nontraditional college students (Zand & Crowe, 1997), low-ability students (Shoaf-Grubbs, 1994), and spatial-visualization challenged students (Galindo-Morales, 1995).

Computational Skills

The fear that students who use the graphing calculator will have an erosion of computational skills is a chronic theme (Fleener, 1995; Futch & Stephens, 1997; Simonsen & Dick, 1997; Zand & Crowe, 1997), even though there is much evidence to the contrary (Heid, 1997; Hollar, 1997; Kinney, 1997). Students who experienced a balance in pencil-and-paper skills and calculator use fared just as well or better than those students who did not use calculators. These fears about calculator use are based in beliefs about mathematics: the post-mastery view of calculator use implies a computation model for mathematics (Fleener, 1994, 1995), and the rule-based view of mathematics implies calculators will harm learning (Futch & Stephens, 1997; Tharp, et al., 1997).

Fleener (1994, 1995) designed her studies to investigate beliefs about calculator use before concept mastery and calculator use after concept mastery. Her objective was to determine some of the underlying attitudes for the post-mastery belief of these teachers. The post-mastery belief means these teachers would not allow calculator use until the concept is mastered by the student. The teachers’ interests were investigated using the Habermasian Interests Scale, which measures a person’s reaction to problematic situations out of human interests that form systematic orientations for that person. Fleener found that those teachers who had the post-mastery belief exhibited a strong control interest on the Habermasian Interests Scale. This control interest of a teacher represents the attitude that the teacher is the authority in the classroom, and the use of calculators before concept mastery would force the teacher to give up some control in the classroom, thus, producing conflict in the teacher's systematic orientation.

Tharp, Fitzsimmons, and Brown Ayers (1997) designed a study that centered around a 4-month telecourse on the use of graphing calculators. Within the design of the study was a planned attitudes or beliefs survey based on a set of statements geared to a rule-based or non-rule based view of mathematics and calculator use. The findings for this phase of the study showed a strong correlation between teachers' views of mathematics and their views of calculator use. Those teachers who hold a more rule-based view of mathematics were more likely to hold the view that "calculators do not enhance instruction and may even hinder it" (p. 558). The second phase of the study looked at journals written about impressions of student reaction to graphing calculators, teacher perception of instructional style, and teacher use of procedural or conceptual lessons. Tharp, et al. found that the rule-based teachers were more likely to focus on the emotional state of the students as opposed to the conceptual understandings of those students. Rule-based teachers tended to shift away from exploratory lessons and back to procedural lessons; there was no difference in the rule-based teachers and the non-rule-based teachers in attempting to teach a procedural lesson vs. a conceptual lesson with graphing calculators. The researchers also reported a positive attitude toward the journaling activities, and some teachers said that the reflective process of journaling had influenced them to change the way they taught lessons, (i.e., conceptual vs. procedural).

Concept Development

Developing understanding of the big ideas of mathematics is difficult for many students. The graphing calculator can be a tremendous help for studying functions and the properties and characteristics of their graphs (Hollar, 1997; Kinney, 1997). This deeper understanding flows from reading and interpreting graphs and correlating the graph to the equation (Ruthven, 1990), which implies a better understanding of the relationships among the graphical, numerical, and algebraic representations of functions. A few studies (e.g., Giamati, 1991; Upshaw, 1994) indicate that the calculator may have interfered with learning the concept, but other factors such as learning how to use the calculator may have confounded these findings.

Giamati (1991) and Upshaw (1994) worked with students on transformations of functions and graph-exploration-based advanced placement calculus, respectively, using the graphing calculator. In these studies, the student achievement levels were not what the researchers expected. The researchers thought that the multiple representations capability of the graphing calculator would benefit the students. They concluded that the graphing calculator might have hindered students in developing connections about the concepts they studied because students sometimes made erroneous connections or conclusions. However, upon closer examination of the context of the studies, it is more likely that the short treatment period of the studies is the cause for the adverse effects the studies report. Students just did not have enough time to become facile with the calculators before the data collection phase of the study ended.

Problem Solving

Problem solving has long been promoted as one of the best ways to teach and learn mathematics—some would say the only way. If this statement is correct, then promoting problem solving and problem solving skills is a necessity for mathematics educators. The graphing calculator is a tool that helps accomplish this goal. Those students who used the graphing calculator in mathematics instruction exhibit greater success on tests of problem solving (Keller & Russell, 1997; Runde, 1997; Siskind, 1995), more flexibility in approaches to problem solving (Slavit, 1994), more willingness to engage in problem solving and for longer time periods (Mesa, 1997), and more concentration on the mathematics rather than the algebraic manipulations (Keller & Russell, 1997; Runde, 1997). The graphing calculator creates a computational advantage and quite often leads to the selection of proper approaches to solutions. Dick (1992) claimed similar benefits for problem solving when the graphing calculator is used: freeing more time for instruction, providing more tools for problem solving, and changing students' perceptions of the problem solving process due to fewer distractions from computation and more focus on formulating and analyzing solutions.

Special Groups

Traditionally, some groups have more difficulties with mathematics than others do. The graphing calculator "levels the playing field" (Dunham, 1995) for many of these groups so that they perform as well as or better than most others do. The disadvantages that some groups face are related to different cognitive styles, special circumstances, and learning disabilities. Research studies show that graphing calculator use benefits low ability and at-risk students (Shoaf-Grubbs, 1994), spatial-visualization challenged students (Galindo-Morales, 1995), non-traditional college students (Zand & Crowe, 1997), and those with low mathematical confidence (Dunham, 1995). A subset of studies looked at gender differences in calculator use and reported that females reversed their role of low performance when not using graphing calculators. Surprisingly, male performance dropped when the graphing calculator was added to instruction (Bitter & Hatfield, 1993; Christmann & Badgett, 1997; Ruthven, 1990).

Female students, both girls and women, showed much greater gains in mathematics when using the graphing calculators than did their male counterparts. Without calculators and with the use of computers, female students performed at lower levels than males in a study on statistics achievement by Christmann and Badgett (1997), but when calculators were added to the toolkit of computational aids for the students, roles reversed—females outperformed males. The explanation for this phenomenon is that for females there is a reduction of anxiety about mathematics and an increase in confidence in doing mathematics (Bitter & Hatfield, 1993; Dunham, 1995; Ruthven, 1990). However, Jones and Boers (1993) suggest that males are “deskilling” in algebra, not that females are given an “edge” by graphing calculator use.

Classroom Discourse

A major focus of the NCTM *Standards* (1989) was creating mathematical discourse in the classroom. This discourse promotes the sharing of ideas to create an open learning environment. The graphing calculator becomes a major tool promoting this discourse when used in the mathematics classroom (Farrell, 1996). Farrell noted that students become more active in the classroom, often consulting the calculator as frequently as they consult the teacher. Students are more prone to do group work that involves problem solving, investigations, and explorations. Dick and Shaughnessy (1988) and Slavit (1996) all stated that teachers shift emphasis from lecture classes to investigations and explorations, and Slavit (1996) found higher levels of discourse with more analytical questions asked by students who used graphing calculators in mathematics classes.

Errors from Calculator Use

The graphing calculator is not a panacea for woes in mathematics teaching and learning. In fact, too much of a good tool creates other problems. Students who constantly use the calculator often think that all functions are continuous (Slavit, 1994), and that misconception then limits the example base rather than expanding it. The tolerance issues of graphing calculator technology may be at fault in this instance. Calculator graphs do not show asymptotes as we have traditionally represented them. For this reason, it is difficult to "zoom in" on discontinuities that are single points. On other graphs, correct representation is not possible because the calculator does not have enough pixels on the screen.

Other difficulties students encounter are concerned with scaling and domain and range (Wilson & Krapfl, 1994). Students often think the domain is a subset of the range, and flexible scaling needed for different window settings causes students to confuse the underlying definition of scale (Dunham & Osborne, 1991). Wilson and Krapfl discussed problems students developed with scaling. When examining a graph on the calculator, adjustments can be made so the viewing window actually looks at a larger area of the coordinate plane. This increased viewing area is accomplished by changing XMIN and XMAX on the window menu of the calculator, features for controlling the window on graphing calculators. Although students often get the results they expect, oftentimes some students cannot explain what effect changing the viewing window had on the results. Therefore, "Teachers must recognize that experts sometimes see relationships that are missed by students" (Wilson & Krapfl, 1994, p. 259).

Uses of Graphing Calculators

Simmt (1997) worked with six inservice teachers who taught the same unit—transformations of quadratic functions. Likewise, Ebert (1994) worked with preservice teachers in a mathematics methods course during their unit on functions where each preservice teacher taught the unit on functions. In both studies, one aspect the researchers looked at was how the graphing calculator was used. Simmt found the teachers in her study used the calculator in the following ways: 1) checking work, 2) plotting graphs of functions, 3) finding graphical solutions, 4) understanding word problems, 5) exploring beyond the concept being taught, and 6) providing a picture. For the preservice teachers in Ebert's study, she found that the teachers used the graphing calculator to 1) examine the graph, 2) make predictions graphically, 3) confirm algebraically, and 4) make connections between graphical and algebraic representations.

In both studies, the researchers worked with teachers whose unit of study focused on quadratic functions. The expectation is that the categories of use for the graphing calculator would be similar, and, in fact, the categories of use of the calculator from both studies are about the same. The notable difference is that the list of uses from Simmt's (1997) study is more complete because the list enumerates a wider range of uses for the same topic than the list from Ebert's (1994) study. I suspect the difference can be traced to the experience levels of the teachers involved in the studies, inservice teachers vs. preservice teachers.

Role of Graphing Calculators in School Mathematics Reform

The question is not whether mathematics has changed, but how it has changed with the advent of graphing calculator technology. The example of history shows us that it must change. Waits and Demana (2000) stated that the graphing calculator was the first "hand-held computer and the significance should not be underestimated" (p. 72). Before the availability of the graphing calculator, teachers most often used computers and graphing software as demonstration tools for graphing; students very rarely used these resources. If the high school was fortunate enough to have a computer laboratory where students actually used the hardware-and-software tools, many times non-mathematics classes dominated the time in the computer laboratory. (I often experienced this frustration in my former high school.)

When the graphing calculator came on the scene, all students had a computer available to them, provided the school or school district that they attended was foresighted enough to purchase the calculators for student use in the mathematics classroom. The calculator was easy to use, low in cost, and portable (Demana & Waits, 1992).

As teachers became more fluent with the graphing calculator, the structure of the classroom environment began to change. More group work focusing on graphing calculator investigations invited the sharing of ideas about the mathematics that students were learning. Students worked longer at problem solving exercises because the graphing calculator was a convenient tool for doing messy computations (Mesa, 1997), and they could concentrate on the mathematics.

Because the calculator is a convenient tool for computation, the view of computation must change. Waits and Demana (2000) stressed that a balance between pencil-and-paper manipulations and the graphing calculator is extremely important in the appropriate use of the calculator. Wilson and Krapfl (1994) also stressed this importance in balance between calculator-generated solutions and pencil-and-paper manipulations in terms of students understanding the nature of calculator solutions. Oftentimes, they said, the calculator solutions for equations and inequalities are approximations, and students should be aware of the difference.

Appropriate use implies that the student solves analytically with traditional pencil-and-paper algebraic methods and supports that solution with the calculator. The student might solve the problem using the graphing calculator but also should confirm with appropriate algebraic methods. In addition, the student can solve using the calculator when traditional methods make the mathematics too tedious, too time-consuming, or richer (Waits & Demana, 2000; Wilson & Krapfl, 1994). This type of computation, then, is technological computation. Pencil-and-paper computation is the confirmation of calculator results, and mental computation is estimation and actual computations that can be done without pencil and paper (Waits & Demana, 2000). These changes in mathematics require training teachers in new methods. Moreover, that training must be sustained and in fairly large amounts (Jost, 1992; May, 1994; Waits & Demana, 2000) if we expect teachers to make permanent changes in pedagogy concerning the use of graphing calculator technology.

Heid and Baylor (1993) reviewed research for the broader implications in the mathematics classroom regarding the use of computers and calculators.

> To a greater extent than almost any other educational innovation, computing technology has the potential for wide-ranging and long-lasting impact in the mathematics classroom. A wholehearted incorporation of computing technology in high school mathematics suggest changes in mathematical content as well as in the methods and nature of teaching and learning mathematics. (p. 198)

The implications that the authors discussed involving the graphing calculator included both how the content of mathematics is taught and changes in classroom dynamics. Because the graphing calculator displays function graphs, such equations as $4x^2 - 3x + 5 = 9x - 1$ become relatively simple to solve. The equation is split into two functions: the first, $4x^2 - 3x + 5$; the second, $9x - 1$. Each function is graphed on the same axes, and the intersection of the two graphs is found. The method for finding the intersection is using the ZOOM key on the graphing calculator. With this facility on the calculator, the solution can be found within the tolerance of the graphing calculator.

In the traditional classroom, the teacher sets the mathematical tasks the students are to do. Quite often in calculator-enriched environments, students assume the role of task setters. Heid and Baylor (1993) reported that Heid, Sheets, and Matras observed classes where students finishing explorations posed questions growing out of the exploration, thus extending the day's assignment and investigating more deeply the mathematics generated. In another study reported by the authors, students challenged each other to "prove it," and they produced examples and non-examples for their conjectures. Another researcher, Rich (1991), found a role reversal for the teacher. In a class exploration, the teacher worked side by side with her students to solve the problem in question. This role reversal allowed the students to see the teacher as a problem-solving role model, actually a colleague with her students.

Beliefs

Milton Rokeach (1960) reported a large amount of interest in the study of the nature of beliefs near the beginning of the twentieth century. Social psychologists were curious about the effect that beliefs had on people's actions because they thought beliefs might be a method to predict actions. However, this interest waned with the realization that it was very problematic to access these beliefs and to formulate a method by which to study them. Then, in the 1930s, behaviorism emerged and became a major thrust for social psychologists.

Beliefs had a slight renaissance in the 1960s (Thompson, 1992). When cognitive science appeared in the 1970s, beliefs again were important in the study of human cognition, and this interest became stronger as more and more disciplines recognized the significance of beliefs in society, both politically and culturally. In education, the focus on beliefs developed from a change in research focus from teacher behaviors to teacher thinking (Munby, 1982).

Belief Systems

The definition of a belief system, according to Rokeach (1968), is an object that contains all the "beliefs about physical and social reality" (p. 2) for a given believer. These beliefs are placed in a psychological hierarchy—some have greater strength and intensity than others. Those beliefs with strong intensity are more centrally held; those beliefs with less intensity are peripherally held. A centrally held belief is connected to more beliefs. He used the analogy of the atom.

The atom has a nucleus of very tightly held particles that are extremely difficult to split apart. Other particles spin around the outside of the nucleus of the atom, and these particles are held less strongly. In fact, in the presence of other atoms, the particles are pulled away from the original nucleus. The nucleus is like a central belief because a central belief is extremely difficult to change; the outer particles, or electrons, represent the peripheral beliefs because these beliefs can be changed more easily.

Rokeach (1968), as well as Green (1971), proposed a hierarchy of beliefs that could be called substructures. These substructures contain the attitudes or values of the believer. Attitudes develop toward one's beliefs, and these attitudes can be expressed as beliefs. Green said that a belief about another belief is a *value*. Pajares (1992) put it this way:

> In all, it [a belief system] is a conceptual model with a very simple premise: Human beings have differing beliefs of differing intensity and complex connections that determine their importance. (p. 318)

Green's 1971 book *The Activities of Teaching* outlines belief systems in terms of three dimensions: the way in which beliefs are related to each other within the system, the degree in which the beliefs are held (often called the psychological strength), and the cluster effect that isolates one subset of beliefs from another subset in the system. This structure for a belief system is very similar to Rokeach's

(1960) design, which also contains three dimensions. He called these dimensions belief-disbelief, central-peripheral, and time-perspective.

Green (1971) specifically stated that the content of the belief is not the important aspect to investigate but the relationship of one belief to another. No belief is totally independent from another; in fact, beliefs always occur in "sets or groups" is Green's first dimension. Suppose a teacher believes that it is her responsibility to create an open learning environment for her students. To support this belief, the teacher uses classroom discourse and promotes the mathematical confidence of her students. The conceptions (Thompson, 1984, 1992) that classroom discourse and promoting mathematical confidence build an open environment are both separate beliefs. Thus, no belief is held independent of any other belief; beliefs always come in groups or sets.

I disagree with Green's assessment that the content of a belief is not the important element for study. I understand that in certain contexts, studying the content of the belief has no relevance, and, thus, one would examine how the beliefs are held. For this study, the content of the belief is important because it was the content of beliefs that led to my understanding of how and why two preservice secondary mathematics teachers decided to use the graphing calculator in mathematics instruction.

Green (1971) called some beliefs *primary*, and others he called *derivative* beliefs. The "create an open learning environment" belief is a primary belief, and the "use classroom discourse" and "promote mathematical confidence" beliefs are derivatives of the primary belief because they developed out of the primary belief. This structure gives belief systems a quasi-logical orientation.

This quasi-logical structure of belief systems leads to Green's (1971) second dimension that refers to the degree in which the beliefs are held or the psychological strength of the belief. *Psychological strength* is the measure of significance that the belief has for the believer. Those beliefs that are psychologically central for a given believer are most strongly held, (i.e., hardest to change). Again, the content of the belief is not important but *how* the belief is held is important. Therefore, Green would say that beliefs are *central* or *peripheral*; the central beliefs have the greatest resistance to change while the peripheral beliefs are the ones most easily challenged and changed.

The third dimension of Green's (1971) structure relates to a property of beliefs. This property is the clustering characteristic of beliefs.

> Beliefs are held in clusters, as it were, more or less in isolation from other clusters and protected from any relationship with other sets of beliefs. (p. 48)

The illustration about the "create an open learning environment" belief is a cluster of beliefs containing a primary belief and two derivative beliefs. Green likened these clusters to sets of concentric circles in which the circles of greater radius form a buffer to other clusters of beliefs that might be in conflict with the original cluster. The buffer protects the primary or core belief, in terms of Green's analogy, the belief represented by the circle of smallest radius. In this fashion, a teacher can hold inconsistent beliefs without experiencing any turmoil. The turmoil occurs when "the beliefs are set side by side and their inconsistency revealed" (p. 47).

Green (1971) labeled these inconsistent beliefs as those that are held *nonevidentially*, (i.e., there is no evidence to support the tenet of that belief). These beliefs are what Green might call "just because" beliefs. The believer might be unable to explain the reasons for the belief; it's just there in her belief system. If a believer has evidence for a belief, sometimes called grounds, then the belief is said to be held *evidentially*. It is this belief that can be more easily changed if the grounds for changing it are convincing enough for the believer.

Impact on Teaching Practice

In her chapter in Grouws' handbook, *Teachers' Beliefs and Conceptions: A Synthesis of the Research*, Thompson (1992) asserted:

> The nature of teachers' beliefs about the subject matter and about its teaching and learning, as well as the influence of those beliefs on teachers' instructional practice, are relatively new topics of study. As such, these topics constitute largely uncharted areas of research on teaching (p. 130).

She continued to say that several studies showed the importance of teachers' beliefs about mathematics and mathematics teaching in shaping the instructional practices of those teachers. One theoretical paper she highlighted was by Ernest. From this paper, Thompson extracted Ernest's key points concerning influences on the practice of mathematics teaching. Those key points are 1) the teacher's knowledge of mathematics and her belief system about mathematics and mathematics education, 2) the teaching context and its constraints, and 3) the extent and degree to which the teacher is reflective about her practice. Knowledge of mathematics is certainly important in the practice of a mathematics teacher, but that knowledge is not the controlling factor in practice. Beliefs about mathematics and its teaching and learning permeate the actions of teachers. Evidence of this difference is seen when two teachers of approximately the same mathematical background exhibit very separate practices. More often practice is affected by "their conceptions of the nature and meaning of mathematics, and on their mental models of teaching and learning mathematics" (Thompson, 1992, p. 131). These mental models of teaching and learning mathematics develop from earlier experiences that shape the belief systems of teachers.

Interestingly, but not surprisingly, the importance of belief systems in other areas of study besides teachers and teaching continues to emerge. These studies focused on student performance and teacher and student cognition. In all of these groups, the study of beliefs has surfaced as a valuable avenue of investigation for mathematics education.

Fleener (1994, 1995) worked with inservice and preservice teachers to investigate beliefs about calculators in which she combined two frameworks for the study. She used the contextual framework of the classroom and community culture along with individual beliefs, knowledge, and self-concept. In the same vein, Tharp, Fitzsimmons, and Brown Ayers (1997) studied inservice teachers and their use of the graphing calculator after an interactive telecourse introduced them to the calculator. Tharp, et al. found that teachers with a non-rule-based view of mathematics were significantly different from rule-based teachers in their views about calculator use, about students' conceptions when using a graphing calculator, and about the instructional style they chose for teaching.

The frameworks used by these researchers centered on the recognition that teachers' beliefs about mathematics and mathematics education affect their teaching practice, and other research that indicates change in teacher beliefs is preceded by changes in practice, all of which is a slow process (Guskey, 1986). Guskey's findings showed that teachers involved in staff development programs exhibited little change in their beliefs until those teachers actually tried the technique suggested by the program and found increased student achievement with the technique. Then, and only then, did beliefs begin to change. Therefore, in both studies, the researchers found that teachers' beliefs about mathematics strongly influenced their use of calculators. For Fleener's (1995) study, beliefs about the mastery issue determined the practice of the teacher. And, for the Tharp, et al. (1997) study, beliefs about mathematics as a rule-based discipline determined the types of practice of these teachers. In a case study, Shealy, Arvold, Zheng, and Cooney (1993) reported a change in beliefs about mathematics for a teacher who used the graphing calculator. The teacher Shealy, *et al*. studied was using the graphing calculator in his teaching. As he saw the results of improved knowledge in his students, his beliefs about mathematics and how it should be taught also began to change. This instance of the Guskey (1986) phenomenon suggested that teachers who change their beliefs about mathematics after using the graphing calculator might move toward teaching practices strongly encouraged by NCTM standards.

So, although some work has been done to understand the effects of beliefs and belief structures of inservice and preservice teachers, we still need more information about the connections between practice and beliefs. Understanding these connections can give us a more informed view of how to affect change in instructional practice.

Connections to Other Research

Two other pieces of literature informed my thinking and helped me understand the preservice teachers' views and beliefs about teaching mathematics and the concerns they fostered while teaching mathematics during the student teaching field experience. Kuhs and Ball (as cited in Thompson, 1992) identified four separate views held by teachers of how mathematics should be taught. Those views were 1) learner-focused, 2) content-focused with an emphasis on conceptual understanding, 3) content-focused with an emphasis on performance, and 4) classroom-focused. Briefly, the *learner-focused* view holds that the student is actively involved in doing mathematics; the *content-understanding* view holds that content is the focus with an emphasis on conceptual understanding; the *content-performance* view holds that content is the focus and drill is the method; and, the *classroom-focused* view holds that knowledge about effective classrooms is applied to the teaching of mathematics.

Fuller and Bown (1975) identified three stages of concern through which preservice teachers progress as they gain experience in the classroom. These concerns develop out of the context of the classroom. The first stage of concern is related to coping with classroom issues, usually management. From this stage preservice teachers move to concerns about teacher actions in the classroom, and, in the third stage, preservice teachers examine student learning in terms of teacher actions and how effective those actions were for student learning. Likewise, Schwab (1973) discussed areas of concern for inservice teachers, but he did not assign a specific order to these areas. Schwab related the areas as context, content, teaching, and students. Both preservice teachers exhibited concerns in all three stages identified by Fuller and Bown, and they exhibited concerns in three of the four areas identified by Schwab.

Theoretical Framework

As I began formulating this research study about graphing calculator use, I considered the elements that might influence that use, based on my personal experience and my reading of the literature. I hypothesized that teachers' beliefs, teachers' personal knowledge of graphing calculators, and local constraints on calculator use would influence preservice teachers' graphing calculator use in mathematics instruction.

My overarching goal in this study was to identify how and when preservice teachers use graphing calculators and then to tie this data to their beliefs, knowledge, and local teaching situation. Therefore, I began by identifying the ways in which preservice teachers used graphing calculators in instruction, using Simmt's (1997) categories of use as a starting point. Then, I attempted to determine how each preservice teacher's beliefs (about mathematics, teaching, students, and technology) might be leading to these uses by applying Green's (1971) metaphor for the structure of belief systems. I attempted to determine which beliefs were core vs. derivative, central vs. peripheral, and connected vs. clustered in order to uncover the relationship between the beliefs and graphing calculator use. For example, I hypothesized that the belief that mathematics is a sense-making activity might lead to teaching mathematics through discovery and investigative techniques. The teaching style that uses discovery and investigative techniques then might lend itself quite easily to the use of graphing calculators in mathematics instruction.

Thompson (1992) warned that teachers' beliefs and actions do not always match due to other internal or external circumstances. Therefore, I looked for examples of circumstances where internal or external factors constrained or enhanced the preservice teachers' use of the graphing calculator. An example of an internal circumstance is the teachers' knowledge of the calculator and its capabilities. Examples of external constraints include student resistance, parental and collegial opinions about practice, and classroom management issues of security and access. Figure 1 depicts the relationships I was seeking to uncover.

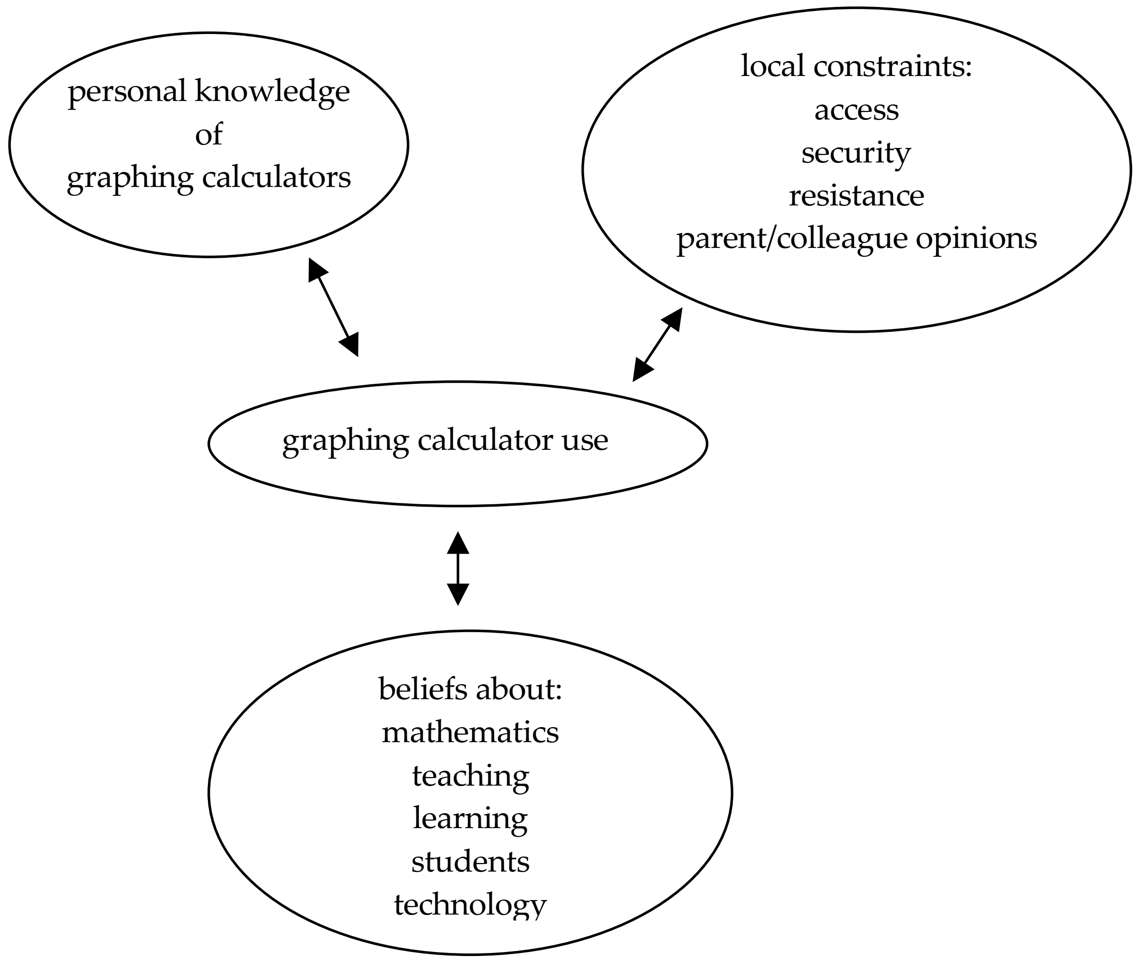

Figure 1: Theoretical framework

CHAPTER 3

METHODOLOGY

Several attributes determine whether a study is qualitative or quantitative. In general terms, a qualitative study is one that "relies on a few cases and many variables," whereas a quantitative study "works with a few variables and many cases" (Creswell, 1998, pp. 15 -16). The purpose of this study was to investigate the decisions that preservice secondary mathematics teachers make when using graphing calculators in mathematics instruction. The research questions guiding this study, therefore, asked *how* and *when* the calculator was used, *what* was problematic about this use, and *what* affected the decisions to plan or not to plan use of the graphing calculator. These *how*, *when*, and *what* questions are typical of a qualitative study.

Other attributes that pushed me to choose qualitative research were the kinds of activities in which it would be necessary for me to engage to complete the study. My topic needed to be explored by committing extensive time in the field for observations and interviews. I did not assume that the factors that influence calculator use have all been identified. Therefore, it was necessary for me to attempt to uncover additional uses of the graphing calculator rather than attempting to ferret out quantitative relationships between known variables. Because I was the lone researcher, how much I could manage to study individuals in their natural setting limited the number of cases that I used. Presenting a detailed view of the topic required large amounts of writing that were descriptive, and claims were supported by numerous quotes from participants. Therefore, all of these attributes led me to select a qualitative design for this study.

Background for the Program

The study was conducted during the spring semester of the 2000 – 2001 school year. The setting was the course EMAT 5460, Student Teaching in Secondary Mathematics Education, and the course EMAT 4950/6950, Professional Seminar in Mathematics Teaching, the capstone courses for preservice secondary mathematics teachers at the University of Georgia. The course EMAT 5460 was completed in the first 10 weeks of the semester and the course EMAT 4950/6950 was completed in the last five weeks of the semester.

The course for student teaching is designed to provide preservice secondary mathematics teachers a field experience that immerses them in school life and the life and role of a secondary teacher and all the responsibilities that life and role entail. The seminar course is designed to provide preservice teachers with an opportunity to discuss and reflect on the student teaching experience as well as provide some practical information, for example, about job interviews, about school law, and about classroom management.

Selection of Participants

In the fall of 2000, I observed six sessions of the secondary mathematics methods course, EMAT 4360/6360, because these students formed the pool of students who were student teaching in the spring of 2001. The enrollment for EMAT 4360/6360 was 23 students, but four of those students did not student teach. Thus, 19 students from the EMAT 4360/6360 course taught in the fall of 2000 and one student from EMAT 4360/6360 taught in the fall of 1999 comprised the 20 student teachers for the spring of 2001.

At the time I began my observations in the methods course (EMAT 4360/6360), another researcher in our department had chosen six of the 20 students as participants for his study. To avoid a possible source of contamination of data, I immediately eliminated those six students from my consideration. From the remaining 14 students, I chose three prospective participants for my study.

I used several criteria for choosing the prospective participants for my study. The primary requirement for the prospective participants was reflective thinking, which I assessed during observations. In these observations, I first looked for students who were willing to share their ideas and opinions in the class discussions. I thought this might be a good indication of how communicative they might be in the interview venue. Secondly, I looked for students whose comments indicated more than a shallow level of thinking about the issues being discussed in class. I was not able to observe the class participation of the young woman who took the methods course in 1999. I consulted with other members of the department who previously taught this young woman, especially the teachers of her EMAT 4360/6360 course; she was very highly recommended in all cases.

The second requirement I used in this process related to the circumstances at one of the high schools involved with student teaching and placement of student teachers. In this particular high school, two of the mentor teachers have a class set of graphing calculators available at all times and use graphing calculators in mathematics instruction. I wanted to include the student teachers assigned to these two mentor teachers because I thought the philosophies of these mentor teachers about graphing calculator use might exert a strong influence on how and when their student teachers use graphing calculators in mathematics instruction. Further, these student teachers definitely had the opportunity to use graphing calculators in their instruction if they so desired. The young woman who took the methods course earlier was assigned to one of these two mentor teachers. An additional benefit of choosing the student teachers at this school was the fact that having only one school in which to observe aided me in the management of data collection.

All three prospective participants were Caucasian females, ages 21, 28, and 40. One was a senior in mathematics receiving the Bachelors of Science in Mathematics degree with secondary certification; the second was a senior in mathematics education receiving the Bachelors of Science in Education degree; and the third had earned a Masters in Mathematics degree and was seeking secondary certification. At this time, I had no knowledge of or evidence about the familiarity or comfort levels with graphing calculators of any of the prospective participants. However, I knew that several of the courses offered in the Department of Mathematics Education at the University of Georgia planned for and required the use of graphing calculators. The prospective participant with a major in mathematics seeking secondary certification opted not to participate in this study.

Data Collection

Prior to the start of student teaching, I collected some preliminary data. The preliminary data that I collected consisted of the following:

- a mathematics autobiography essay (See Appendix A.),
- the AIM – AT – Version II survey (See Appendix B.),
- a portion of the RADIATE/PRIME surveys (See Appendix C.)

I have used the mathematics autobiography questions with my students in EMAT 3400, the early childhood education mathematics methods course, and have gained much insight about students' attitudes toward mathematics and teaching. By asking the students to write an autobiography, I hoped to gain some insight into their current views and beliefs about mathematics teaching and learning. The

Attitude Instrument for Mathematics and Applied Technology – Version II (AIM – AT – II) was developed by Fleener (1995) in her work about calculator use. This instrument, using Cronbach's alpha, had an internal reliability measure of 0.67 for the preservice teachers with whom she worked. This instrument was designed to "focus on beliefs about how calculators can be used and the consequences of calculator use. Forced Likert scaled items were designed to encourage participant reflection" (p. 363). While I understand a Likert scale has limitations, I wanted to use this instrument because it had been validated in the earlier study (Fleener, 1995), and it served as a good springboard for interview questions because of responses to individual items about the participants' current views and beliefs about graphing calculator use.

The portion of the RADIATE/PRIME instrument that I used is questions designed to look at the beliefs of preservice secondary mathematics teachers about the teaching and learning of mathematics, used specifically in 1994 and 1995. These same questions, with one small change, were used in the spring of 2000 to assess the beliefs of mentor teachers in another research project (cf. Wilson, Anderson, Leatham, Lovin, & Sanchez, 1999) about the teaching and learning of mathematics. (Actually, these "questions" are in the form of simile statements with explanations requested that elaborate on the meaning the responder attributed to the statements. The responder was asked to comment on two aspects: what it was like and what it was NOT like to teach/learn mathematics.) I was a researcher for this project at that time and completed two follow-up interviews based, partially, on these items.

I followed this phase of data collection with an interview of each participant to obtain a better understanding of what was written in the mathematics autobiography, and the responses to the AIM – AT – II survey and the RADIATE/PRIME survey questions. These preliminary data provided information about the dispositions of the participants toward graphing calculator technology and helped me know each participant better. As I did in the pilot study that was conducted during the winter and summer of 1998, I used this first interview to assess each participant's experience and familiarity with graphing calculator use. The major portion of the preservice teachers' participation was during student teaching in the spring of 2001. Each participant was asked to sign a contract that outlined time requirements and activities of the study. (See Appendix D.)

A pilot study was conducted during winter and summer quarters of 1998 at the University of Georgia. The winter quarter investigation concerned the perceptions of two preservice teachers about the advantages of graphing calculator use in mathematics instruction before student teaching. The summer quarter investigation concerned the perceptions of one preservice teacher about the advantages and disadvantages of graphing calculator use after student teaching. The second preservice teacher opted not to participate in the pilot study during summer quarter that year. The major finding of the pilot study was that the experience of student teaching tempered the beliefs of the preservice teacher about graphing calculator use. Thus, I wanted to see *what factors during student teaching* influenced decisions about graphing calculator use.

Data collection for this study proceeded in phases. First, I collected the survey data and autobiographies, and then I designed interview protocol from these data. During the first week of student teaching, I interviewed both participants about data in the preliminary sources.

Second, I observed each preservice teacher for one class period twice during weeks 3 through 5 of student teaching to document her teaching practices and her use (if any) of graphing calculators. When the student teacher taught a class that lent itself to the use of graphing calculators, I observed those mathematics lessons that could use graphing calculators during instruction. I asked the preservice teachers to provide me lesson plans, via e-mail, two days before the observations. If the preservice teacher used the graphing calculator, I looked for the categories of use, (i.e., as specified in Simmt's (1997) study). If the preservice teacher did NOT use the graphing calculator, I asked what she thought about as she planned the lesson and then asked about possible ways to use the graphing calculator now that she had the perspective of having taught the lesson. These observations formed the basis for an interview soon after the second lesson was taught. During the interview, I asked questions about how the student teacher decided to use the graphing calculator in the lessons I observed, if the calculator was used. If not, I asked questions about the possibility of graphing calculator use and just how she would accomplish this use. I also asked questions to determine if the student teacher was using graphing calculators in lessons that I did not observe. If so, I asked questions about how the calculators were used. After the first set of observations, I sent e-mail prompts with questions, (e.g., How might graphing calculators help you "take the fear out of math?"), for the participants to answer via that medium.

Third, I observed each preservice teacher for a class period twice during weeks 7 through 9 of student teaching. This period fell during the time when the student teacher was in full control of the teaching and management of her classes. Again, I interviewed her using the same timeline as previously described. These observations and interviews allowed me to describe her calculator use and further probe her ideas about calculator use in mathematics instruction.

Finally, as one of the assignments in EMAT 4950/6950, the Professional Seminar in Mathematics Teaching, I asked the class to write a "letter" in response to a parent criticism of graphing calculator use in an Algebra I class. The purpose of this data collection activity was to give the participants a chance to articulate their views about graphing calculator use in a real-world context. When I have used a similar assignment in EMAT 3400, students have often revealed beliefs about calculator use that contradict other statements they have made. Being faced with justifying one's practice to a parent seems to bring forth a different type of rationale from students. Thus, I used this data collection task as a way to triangulate other data I collected. I also asked the class to write a "philosophy of education" based on their beliefs about mathematics, about teaching, about learning, about students, about society, and about schools. This assignment gave me a wealth of information about the two preservice teachers' beliefs about mathematics and mathematics education.

Data Analysis

The data were analyzed using grounded theory methods. Grounded theory methods are based on the constant comparative method of data analysis. This method involves inductive, concept-building processes that are consistent with qualitative research (Merriam, 1998). Grounded theory is comprised of categories, properties, and hypotheses that link the concepts of each one of these aspects of the grounded theory. The constant comparative method does what the term suggests. The researcher is constantly comparing data with analysis of other data to compare the data with the preliminary categories and properties already derived from the data.

The researcher begins with an event in an observation or interview and compares it with an incident or event from another interview, field notes, or other document. From these comparisons, emerging categories begin to form. Comparisons of these categories continue until a theory develops (Creswell, 1998; Merriam, 1998). The process involves a continuous cycle of data collection, coding, and analysis; each aspect of the cycle informs every other aspect.

The data I collected were in the forms of field observations of classroom practices, individual interviews, e-mail prompts and responses, and essays. During the first pass through the data, I looked for and coded data in terms of beliefs about mathematics, about teaching mathematics, about learning mathematics, about students, and about technology. Second, I looked for personal knowledge of the graphing calculator in terms of benefits of and experience with the use of graphing calculators. And, finally, I looked for local constraints on the use of graphing calculators: availability of the technology, influence of the mentor teacher, content concerns and graphing calculator use, student familiarity with the technology, classroom management issues, appropriate amount of use, and student resistance.

After this initial pass through the data, I then used Simmt's (1997) study to identify my preservice teachers' uses of the graphing calculator. Upon consideration of my data, I collapsed three categories of use into a single category of use, and I identified two novel uses from my data. Finally, I looked at the data in terms of mathematical content to determine the range of mathematics with which the graphing calculator was used. The content areas that were evident from the data were computation and algebra.

Role of the Researcher

Prior to becoming a full-time doctoral student at the University of Georgia, I taught secondary mathematics for 20 years in public school systems. My undergraduate degree was in mathematics with elective credits filled to gain teacher certification. This certification was very much like the program at the University of Georgia. My master's degree was in mathematics education and was earned in summers and at night while I was teaching full-time.

Subjectivity is a concern in qualitative research because the researcher is the main instrument for gathering and analyzing data. The concern arises because the researcher is human and being human implies fallibility. Being human also implies that the individual brings certain values to the research, (i.e., the influences the researcher has on the research). The problem for the researcher, then, is how to account for his or her subjectivity and how to keep it under control.

One of the primary responsibilities of the researcher, related to accounting for subjectivity, is an up-front admission of his or her personal framework – what are my personal experiences, why did I choose this topic, what assumptions am I making for the study, and what insights do I have from the literature that influence my thinking. Providing this information gives the reader evidence of the researcher's interests and the questions that researcher is likely to ask. This information may also provide some intuition about the meaning that the researcher sees in the data.

Qualitative researchers use various metaphors to describe the relationship between the observer and the observed – self and other (Fine, 1994; Heshusius, 1994) and a managed distance (Creswell, 1998) are two about which I have read. Merriam (1998) posits five categories that describe the relationship:

1. *Complete participant*: researcher is a member of the group concealing the observer role
2. *Participant as observer*: researcher is an observer, which is known to the group, and the participation activities take precedence over observation
3. *Observer as participant*: researcher is an observer, which is known to the group, and the observation activities take precedence over participation

4. *Complete observer*: researcher is hidden from the group or a public location is used
5. *Collaborative partner*: researcher's identity is clearly known to all; researcher and "participants are equal partners in the research process" (p. 101).

I agree with Heshusius (1994) and Merriam (1998) that the researcher is part of the research process and cannot totally dissolve the personal relationship described by the biases and experiences of the researcher. In fact, Heshusius (1994) recommends that the researcher should not attempt to divorce herself from personal biases, experiences, beliefs, passions, and emotions, but should attempt to create a state of *participatory consciousness.* This state of participatory consciousness requires the researcher to put aside temporarily any egocentric concerns related to the research. The essential characteristic is that the researcher is concerned with the needs of others during the research. By putting aside egocentric concerns, the researcher enables herself to fully attend to the needs of others in a non-evaluative way.

According to Heshusius, this participatory consciousness is the ideal state in which to undertake qualitative research. She does not offer, however, strategies to achieve or maintain this state of participatory consciousness during the research process. She does mention two qualities that are necessary for an inquiring attitude; those qualities are open-mindedness and receptivity. The quality of open-mindedness reflects the researcher's ability to let the meaning of the data come to her, and the quality of receptivity reflects the researcher's ability to relate to and understand what is studied. This was the view I attempted to adopt for my study.

I did several things to facilitate the qualities of open-mindedness and receptivity. I kept a journal of questions about and reactions to the research. The distance that I traveled to reach the school where my participants did their student teaching was quite far. Because of this distance, I kept a tape and recorder in my car so that I could dictate my thoughts about the day's observation as I drove home from the school. This technique was very useful because it helped me identify questions I needed to ask in the next interview of the participants or e-mail prompts sent to the participants. I sought the aid of a peer debriefer, and I solicited member checks for verification of data and data analysis related to emerging categories during the research process. During the analysis process, I used qualitative research software, *HyperRESEARCH* (Hesse-Biber, 1993), to aid in management of coded data. During the writing process, I sought the aid of colleagues outside of mathematics education (Schifter, 1999) for clarity of "communication with nonspecialists" (p. 2).

I taught EMAT 4950/6950, the Professional Seminar in Mathematics Teaching course; my participants were students in this class. To alleviate any fears or worries that the "performance in the study" of my participants had any effect on the grade received in the seminar, I presented the participants with a contract (See Appendix D.) that outlined the specific needs and time requirements for the study. Likewise, the syllabus for the seminar course was very clear about the assignments required for receiving particular grades in the course. The points for each assignment were explicitly stated so that each student was aware of the importance attached to each assignment for the seminar course.

CHAPTER 4

RESULTS

This chapter describes the conversations and observations that comprise this study. The focus is on the beliefs and practice of two preservice secondary mathematics teachers, Fiona and Hope (pseudonyms chosen by the participants), regarding their use of graphing calculators during student teaching. The data are presented with analysis as guided by the research questions that were outlined in Chapter 1. Each research question is repeated and addressed separately in this chapter.

The data that serve to answer the research questions were collected from some of the classes taught by the preservice teachers during student teaching. Fiona's class of Pre-algebra, a class in which most, if not all, of the students had previously failed the course, provided data from observations and stimuli for our conversations about mathematics and about mathematics education. Likewise, Hope's classes of Applied Algebra[5] and Algebra I provided data for the study.

Participants

The data from the first interview, the mathematics autobiography, the AIM – AT – II survey, and the RADIATE/PRIME metaphors for learning and teaching mathematics helped me formulate the background of each preservice teacher and

[5]Applied Algebra is a course for lower-level students, and the course teaches algebra concepts in the context of applications.

how that background might have influenced the beliefs evidenced in data I collected later. The summary of these initial data sources follows for each preservice teacher.

Background of Fiona

As a young child, Fiona lived in Evanston, Illinois, where she remembered being "moved ahead in mathematics as early as the second grade," though this experience was less than pleasant for her because it consisted of long division worksheets "without much explanation, and [she] remembered being lost." When she was a sixth grader, her family moved to Spring Green, Wisconsin, a very small town. She took Algebra I in the eighth grade and Geometry in the ninth grade (Her teacher for Geometry was a client of her mother's, and "everyone knew it;" her mother was a drug/alcohol abuse social worker.). Her family moved again, and Fiona started high school in tenth grade in Madison, Wisconsin, at a large, urban school that she remembered being "quite good." She was placed in an Algebra/Trigonometry class in which she "did horribly" and always felt "dumb" because the teacher would not help her "catch up." Because of this experience, she opted out of "hard math" and took an easy Probability class. Her senior year found her in the Algebra/Trigonometry class again, doing well, and she graduated early, starting her college career at the University of Wisconsin that same spring.

The stay at the university was short-lived because Fiona said that her father "picked out the school, the classes, a sorority, and a major" and she "fled in terror." She moved to New Jersey where she became a nanny for three years. During that time, at the age of 19, she met and married her husband and she took a few classes at the University of Pennsylvania and at a community college in New Jersey. Later, after moving to Georgia with her husband, Fiona spent four more years as a nanny, and, then, Fiona and her husband decided that it was time to get the education that she had foregone in her younger days.

Her experiences as a nanny had Fiona considering elementary education as a career. However, after the move to Georgia and tiring of the nanny position, she spent a year driving a school bus and substitute teaching; these experiences taught her that "a couple of younger kids is not 30, and [she] wanted to teach something, not deal with management issues such as the recess line."

The "something" turned out to be mathematics because the "earlier aptitude" had appeared again when she took college mathematics classes, and she felt most comfortable with those classes. Another impetus for this direction came when Fiona researched available monies for students and found that mathematics teachers were needed and money was available to help prospective mathematics teachers with school expenses. Because she and her husband did not believe in student loans, these monies allowed Fiona to contribute to the cost of her education. She chose Gainesville College because the school offered her a scholarship, it was a smaller campus where she thought she would perform better since she had been out of school for so long, and she felt she would receive more individual attention. At Gainesville College, Fiona majored in mathematics education, and she graduated in 1999 with the Associate of Science degree (a 2-year program), having done quite well in all her mathematics courses and having received all the mathematics awards the school offered. The Associate degree only provided the beginning mathematics for a secondary mathematics teacher, (i.e., algebra/trigonometry and calculus), and one education course, not nearly enough to gain certification to teach mathematics at the secondary level.

Her decision to come to the University of Georgia was based on the reputation of the mathematics education department. She also wanted contact with mathematics education graduate students because she saw that contact as an important part of her education.

Fiona first used the graphing calculator in college algebra as a tool to enhance her personal learning of mathematics. Because of this positive experience, she continued to use the TI-85 in such courses as trigonometry, calculus, and statistics. Thus, she was most familiar and comfortable with the TI-85 graphing calculator. However, since working with the TI-83+ graphing calculator in her teacher education classes, she decided this graphing calculator model has "the most to offer," and she planned to purchase that model for her personal use. Her experiences in teacher education involved using the graphing calculator for personal problem solving, (i.e., to solve problems posed in her teacher education classes).

Fiona completed her student teaching in mathematics in a high school in rural Georgia that was located northeast of Athens. She chose this school because of its diversity in ethnicity and socioeconomic status. The high school schedule was structured by blocks of time for instruction, roughly 90 minutes per block, and each school day contained four blocks. (My observations of Fiona occurred during Block 1. See Figure 2 for Fiona's schedule.)

Block	Hour	Class/Activity	Description
1	8:00 – 9:30	Pre-algebra	Lower-level students
	9:30 – 9:41	Fast Break	Student social time
	9:46 – 9:51	Channel 70	School announcements
2	9:51 – 11:21	Planning	Lesson prep/grading papers
3	11:26 – 1:26	Euclidean geometry	Upper-level students
	12:11 – 12:35	Lunch	
4	1:31 – 3:01	Euclidean geometry	Upper-level students

Figure 2: Daily schedule for Fiona

Thus, the stage was set for becoming a secondary mathematics teacher after graduation from the University of Georgia in May 2001. Fiona was 28 years old and very excited about her career in teaching; she planned to seek the Master's degree within five years of beginning her career in teaching. This research study was conducted during Fiona's final semester of work completing the Bachelor of Science in Education degree.

Initial Understandings of Fiona's Beliefs

The metaphor Fiona used for learning mathematics was "Learning mathematics is like working a jigsaw puzzle." Fiona explained the metaphor in this way:

> Mathematics takes on many different sizes, shapes, and forms. The learning of mathematics involves trying to understand all those forms, individually and as a whole. A student must appreciate each piece for its own worth; yet understand the concepts of the puzzle when completed. Working a puzzle can be frustrating, yet it is exhilarating when a piece falls into place and thrilling when the project is complete. A jigsaw puzzle not only describes the learning of mathematics, but also simulates the emotional roller coaster I associate with the struggle for comprehension.
> (RADIATE/PRIME survey items)

She said that the "form" of mathematics is related to the procedures and mechanics recognized as algebra or geometry, whereas the shapes would represent the content of those subjects. Fiona thought that the "project is complete" when one reaches

> the end of the problem, not just the answer, but understanding the whole process and why it worked and being able to use it when you go on to something else. (Interview 1)

These statements and further conversations with Fiona told me that she saw mathematics as a discipline that contains content that is connected over the subject areas, such as algebra and geometry. Each of these subject areas can use the other subject area to reinforce the content of that subject and increase the understanding of why procedures work. For example, if one needs the distance between two points on a non-horizontal or a non-vertical line, geometrical knowledge about the Pythagorean theorem and its components aids in the understanding of the algebraic development of the distance formula, which is normally used to calculate the distance between the two points.

Fiona said that she wanted to be a mathematics teacher because her goal was to

> change the way math is perceived by many people. Math is not bad, nor is it a mystery that only a few people can solve. It provides a logical way of thinking that includes assessing situations, making and validating conjectures, and reflecting on the reasonableness of a conclusion. These are skills that are used in many areas of life, not simply mathematics. I want to take the fear out of math, and I want to validate the opinions of all students in a classroom—unlike the embarrassment and shame I remember from my high school mathematics! (Mathematics autobiography)

Fiona's metaphor for a mathematics teacher was that of a gardener. She saw her classroom as a garden where each student is a seed in that garden.

> Gardens begin with a seed (students), and with much care and energy (teaching), the plants grow and bear fruit. A teacher is responsible for opening the mind of the student, and helping that student reach a higher level of mathematical thought. Just like the nurturing required for any seedling, the students require food (knowledge), sunlight (opportunity), water (the tears of hard won success), and a lot of encouragement! (RADIATE/PRIME survey items)

I concluded that Fiona saw the teaching of mathematics as setting an environment for learning that reaches beyond mathematical concepts and applications to preparation for daily life. This environment fosters "a community of students who can work together, value one another's opinions, and take risks to find different paths for solutions." In this learning environment, students voice their ideas during "active discourse," and they work cooperatively as "a community of mathematical learners." Through the learning environment created by the teacher, students grow, not only in mathematical thought, but also in social relationships within the community of the classroom.

Background of Hope

As a child, Hope attended North Springfield Elementary School in Springfield, Virginia, a suburb of Washington, D. C. The family was located there because she described her father as "a government worker." She remembered her third grade teacher as being "an excellent teacher. She thought [Hope] was 'gifted' in math." However, as Hope moved into the fourth, fifth, and sixth grades, her teachers labeled her as "stupid in math" because she could not do the speed drills for the multiplication facts. Hope admitted to me that she never memorized her tables, and she had "tricked [her] mother into signing a paper that said [she] had them memorized."

Hope attended a public high school in the Washington, D. C. area; her mathematics in high school included Algebra I, Algebra II, Geometry, and Algebra/Trigonometry. High school mathematics was not easy for Hope; she told me she failed Algebra II and had to take the course over to gain credit for that subject. She vividly remembered the teacher of this course: "I don't understand why you don't understand this!" the teacher would say to Hope. Hope explained that she had "aced physics, and this frustrated her math teacher [for Algebra II]."

Hope was the mother of two children, a son and a daughter, ages 11 and 7, respectively.[6] She earned her undergraduate degree in 1984 from Georgia Southwestern College, where she majored in computer science and minored in physics. She immediately applied for graduate school, and she earned her Masters

[6] The ages reported here were current at the time of the study.

of Mathematics degree from the University of Georgia in 1987. After completing the Master's degree, she taught Math 100 for two quarters at the university. (Math 100 was an algebra course designed for those students who did not score high enough on their college entrance exam at UGA.) While working on her degree, she served as a research assistant, working with the Advanced Computational Methods Center, which involved helping visiting researchers use the Supercomputer at the center. She also aided a mathematician and statistician in their research. Her "first real job" after graduation was working on a project called COSMIC; her duties included checking software for "bugs," writing abstracts describing the purpose of particular programs, and updating students about the available software in the mathematics department. When she left this job, Hope recommended that they "hire three people to do what [she was] doing…At the time, [she] thought [she] wanted to use [her] math and computer background to do numerical analysis," but that all changed after her son was born and she decided to stay home with him and work from home. The work she did was computer programming for a psychology professor at the University of Georgia. In the meantime, her daughter was born; staying home with her children showed Hope that she would "like to work with children."

Other experiences with children included being a Cub Scout leader and tutoring neighbor children through high school Geometry and Algebra II. During summers, she worked as a lifeguard and taught swimming lessons. These experiences and her background in mathematics and physics pushed Hope to teach secondary mathematics. With this direction in mind, Hope applied to the Department of Mathematics Education at the University of Georgia and began classes to gain certification to teach secondary mathematics.

Hope purchased a TI-83 graphing calculator at the beginning of her teacher education (for certification) program. She thought the graphing calculator was an excellent tool to enhance the teaching of mathematics, and she wanted her own machine so that she could learn more about how it related to different types of mathematics. In her teacher education program, she had courses in which "[they] were taught the key strokes to solve a problem but never really learned how to use it [the graphing calculator]." Hope said that she learned how to use the graphing calculator when she "had to figure out how to solve the problems for [herself]."

Hope's student teaching assignment was in the same rural high school as that of Fiona. She chose this location because of its close proximity to her home. (Four of my observations of Hope occurred during Block 2, and one observation occurred during Block 4. See Figure 3 for Hope's schedule.)

Block	Hour	Class/Activity	Description
1	8:00 – 9:30	Applied Algebra	Low-level students
	9:30 – 9:41	Fast Break	Social time
	9:46 – 9:51	Channel 70	School announcements
2	9:51 – 11:21	Applied Algebra	Lower-level students
3	11:26 – 11:50	Lunch	
	11:50 – 1:26	Planning	Lesson prep/grading papers
4	1:31 – 3:01	Algebra I	Upper-level students

Figure 3: Daily schedule for Hope

In May 2001, Hope received the proper certification to teach secondary mathematics in Georgia's public systems. Hope was 40 years old and looked forward enthusiastically to teaching in the fall of 2001. This research study was conducted during the final semester of Hope's certification process.

Initial Understandings of Hope's Beliefs

"Learning mathematics is like working a jigsaw puzzle." was the metaphor Hope chose to describe this process. She said that learning mathematics is making sense of the "pieces" of mathematics until "the picture becomes clear."

> A lot of times when I first look at a mathematical task, it doesn't make a bit of sense to me. Then, I fit one piece into place or figure one thing out and the rest follows. It's like putting the pieces in until I finish the problem. (Interview 1)

Hope thought that many people learned mathematics by practicing algorithms until "it just becomes automatic." To her, this was absolutely the wrong way to learn mathematics because people miss "the true understanding of why it [mathematics] works." She thought that "the right way" to learn mathematics is "not just how to do it, but why it works." I concluded that Hope saw learning mathematics as a challenge, and that learning should be enjoyable, not dry and boring, and learners should see relationships among mathematical concepts. To relate the excitement and enjoyment of one of her students, Hope cited this example:

> Oh, and somebody did something today in first block. There was a question about if you get a penny a day, and you double it every day for a month, which would you like to have—a million dollars or a penny a day for a month that doubled every day. And he did it on his calculator. And it, you know, he was AMAZED how much money you would end up with after a month. We were doing the exponential function, and he got in front of the class and demonstrated…I told them they ought to go home and ask their moms for an allowance for a penny doubled each day for a month. (Interview 2)

To accomplish the goal of enjoyable learning, I deduced that Hope would "present mathematics" through applications, thus, connecting mathematics to everyday experiences.

The metaphor Hope used for a teacher of mathematics was a gardener.

> I think a math teacher is most like a gardener. She plants a seed and if she tends to the seed, it will grow. If she does not tend to the seed, it will die. (RADIATE/PRIME survey items)

She saw her classroom as a garden where mathematics provided the seeds she planted as a teacher, and her students were the medium in which the seeds or mathematics concepts grew. "Tending the seeds" was teaching or "nurturing" that "promotes growth." She used the example of her first lesson on slope.

> Today in my lesson, I tried to plant the seed of what slope is. OK, now I can't just leave that. I have to go back to it, and tomorrow, I've planned a calculator activity that will investigate the different slopes by plotting them in the calculator. You know it makes sense, the slope, the bigger the number…the steeper the line. We're going to look at positive slope first. And I'm trying to relate it to other things, like the grade. [*Grade* refers to the steepness of a hill on a road.] I just, I have to keep at it; and, then, we're going to introduce the negative slope with an activity for that. Basically, I have to give them an idea and let it grow, instead of giving it all to them at once and having them get it. (Interview 1)

I deduced that Hope saw teaching mathematics as a set of activities that promotes the love of and reduces the fear of doing mathematics.

> I don't see math as being as fun as it could be. I haven't been able to make it as fun as I'd like for it to be…In the math ed classes I've taken the problems we did were just interesting. I wanted to work on them because they were fun—they were like doing a puzzle. I haven't been able to make it fun for my students, I'm trying... But, I think math can be fun just for the sake of what you find out, the relationships you discover. (Interview 1)

The mathematics teacher should present concepts so that the learning is enjoyable and is connected to what has already been learned. The teacher should create a learning environment that is comfortable for every student, encouraging the sharing of ideas and strategies during problem solving.

Contrasting the Preservice Teachers' Beliefs

As I worked through the data answering the research questions for my study, I came to understand which beliefs were driving forces for each preservice teacher as she planned for and taught her classes during student teaching. In Figure 4, I summarize and contrast the beliefs for the preservice teachers. The summary section of the figure shows that the preservice teachers shared many beliefs about mathematics and mathematics education. Some beliefs, however, were different, and I attempt to explain how those different beliefs developed.

	Mathematics	**Teaching Mathematics**	**Learning Mathematics**	**Students**
Both	Sense-making activity	Problem-solving based	Discovery	Critical thinkers
		Classroom environment	Seeing relationships	Active communicators
		Many tools for success		Compute problems by hand
Fiona only	Connected over subjects	Validate student thinking	Connected to relevant exercises	Authority shift
			Vehicle for learning about life	
Hope only	Connected to everyday experiences	Application-based	Use real-world applications	Proper tools for many levels of mathematics

Figure 4: Fiona's and Hope's beliefs

I concluded that Fiona's beliefs developed out of her experiences as a student both before college and during college. Her beliefs about mathematics mirrored her experiences in mathematics classes. The "connected over subjects" belief about mathematics showed her understanding that mathematical concepts pervade the subject areas of the discipline, and this understanding affected her philosophy about how mathematics should be taught in the mathematics classroom.

Fiona said that a mathematics teacher is like a gardener. Upon further investigation, I found that she saw her students as "seeds" that the gardener nurtured to promote growth. This metaphor convinced me that Fiona's approach to teaching was learner-focused (Kuhs & Ball, as cited in Thompson, 1992). Fiona wanted to teach mathematics, but she also wanted to help her students develop good life skills as well.

Fiona's beliefs about teaching mathematics were derivatives of her learner-focused approach to teaching. The "problem-solving based" belief about teaching mathematics was a derivative of beliefs evidentially developed from her studies in mathematics education. It was obvious that she was well-read in this area and that she thought this strategy for teaching mathematics was extremely important for student understanding, but I did not see any evidence of this belief in my observations of her teaching practice. I suspected that the absence of this strategy was due to the content of the mathematics she taught in the Pre-algebra course. The "validate student thinking" belief was mainly derived from her experiences as a student before college. She had a bad experience in a high school class that affected her views of how a teacher should interact with her students, a direct impetus for the "classroom environment" belief, and I thought her mathematics education studies reinforced her views on this issue. I concluded that this belief was held evidentially (Green 1971), based on her experiences as a young student, and, later, as a college student.

Fiona's beliefs about learning mathematics also were derivatives (Green, 1971; Rokeach, 1960, 1968) of her learner-focused approach. She strongly stressed the concept of different learning styles among various ethnic people groups, and she thought these learning styles should be addressed by using relevant exercises for these people groups; thus, the "connected to relevant exercises" belief developed in her thinking but was not exhibited to any great degree in the observations for which I was present. The "vehicle for learning about life" belief about learning mathematics was yet another derivative of her view about teaching students beyond the subject matter content.

Fiona's beliefs about students were consistent with Hope's beliefs. The one difference that emerged was the "authority shift" belief. I thought this belief was a derivative (Green, 1971; Rokeach, 1960, 1968) of the "critical thinker" belief because Fiona stated that she wanted to promote confidence about mathematics in her students. Confidence about mathematics grows as critical thinking skills increase. With this confidence, Fiona's students would recognize correct and incorrect answers for mathematics problems, and, therefore, correct and incorrect methods and understandings, independent of the authority of the teacher.

Because of Hope's previous studies in physics and computer programming, I deduced that her beliefs about mathematics and teaching mathematics were strongly affected by applications. The "connected to everyday experiences" belief about mathematics tied the discipline to activities in which students would normally engage. I viewed this belief as evidentially held (Green, 1971) because of Hope's personal experiences with learning physics. Likewise, the "application-based" belief about teaching mathematics was a natural derivative (Green, 1971; Rokeach, 1960, 1968) of the first belief about mathematics.

Hope used the metaphor that a mathematics teacher is like a gardener. For her, the “seeds” were mathematics concepts that she nurtured so that the concept would grow to its fullest extent, and the student was the “medium” for the seeds. This metaphor convinced me that Hope’s approach to teaching was content-focused (Kuhs & Ball, as cited in Thompson, 1992). Hope wanted to teach mathematics so that students had a strong conceptual understanding of the content.

Hope’s beliefs about teaching mathematics included the “problem-solving based” belief because she thought this strategy was important to increase the understanding of her students. However, as with Fiona, I did not observe Hope employ this strategy. I suspected that Hope felt a “time crunch” from the quantity of curricular materials she was required to teach and the time in which she had to do it. I also thought the push to teach all curricular requirements illustrated Hope’s content-focused approach to teaching.

Hope’s beliefs about learning mathematics were derived from her personal experiences in high school. She told me that she was always better with courses that used real-world examples and applications. Thus, the “use real-world applications” belief was psychologically central (Green, 1971; Rokeach, 1960) in her belief system about learning mathematics, and it was held evidentially within her belief system. I very often saw this belief in action in my observations of Hope’s teaching practice.

Hope’s beliefs about students deviated from Fiona’s in one significant way. This belief was the “proper tools for many levels of mathematics” belief. From the beginning of student teaching and throughout the ten-week period, Hope strongly maintained that all students could do many levels of mathematics if they were provided the proper tools with which to work. I concluded that this was another psychologically central belief (Green, 1971; Rokeach, 1960). Hope’s continued and sustained use of the graphing calculator showed her faith in the calculator as one of those "proper tools" for exploring deeper levels of mathematics.

The two secondary mathematics preservice teachers shared several beliefs about mathematics and mathematics education. This phenomenon accounted for many similarities I saw in the two preservice teachers, and, yet, there were also many differences. The "sense-making activity" belief about mathematics indicated that both teachers viewed mathematics as more than a set of rules and procedures to be learned (consistent with Ebert, 1994; Tharp, et al, 1997), and this view of mathematics indicated a strong tendency toward graphing calculator use, (consistent with Tharp, et al, 1997).

Another psychologically central belief was the "classroom environment" belief about teaching mathematics that should be described as follows: It is the teacher's responsibility to create an environment of learning in the classroom that promotes the success of all students. This belief is different from the "student success" belief about which Cooney (1999) wrote. Cooney said that mathematics teachers were so focused on students having "fun with math" that they often "shielded" students from "hard thinking" about the concepts they were teaching. My two preservice teachers never exhibited this "student success" belief in their practice. In fact, they often pushed their students to do the "hard thinking" to reach goals that the teachers had set for the day's lesson.

In the preservice teachers' beliefs about teaching mathematics was the "many tools for success" belief. For this belief, the term *tool* included a strategy, an approach, a graphing calculator, or a piece of software for a computer. Each of these tools served to reinforce the success of the teachers' students in the classroom environment the teachers created for those students. I viewed this belief as a derivative (Green, 1971) of the "classroom environment" belief because the tools the teacher used in her classroom directly supported the environment that fostered the success of her students.

Both preservice teachers professed the importance of student inquiry in learning mathematics, and the "discovery" belief was evident in the teacher actions that I observed during student teaching. Hope said that learning mathematics is "not working on an assembly line because that activity required no thinking beyond the present task." The "seeing relationships" belief about learning mathematics encompassed thinking about connections to previous knowledge and thinking about how the components of mathematics were related. I recognized the "seeing relationships" belief about learning mathematics as psychologically central (Green, 1971; Rokeach, 1960) for both preservice teachers.

The preservice teachers' beliefs about students were also consistent. The most psychologically central (Green, 1971; Rokeach, 1960) of these beliefs was the "critical thinker" belief. Both preservice teachers encouraged the development of these critical thinking skills through questioning and thought-provoking activities. The "active communicators" belief was a natural derivative (Green, 1971) of these activities, (i.e., the activities forced students to communicate with the teacher as well as with other students in the class). Fiona and Hope expressed the need for students to have proficient computational skills, and the recognition of that need led to the "compute problems by hand" belief.

The Problematic

The first research question that guided this study was, "*What do preservice secondary mathematics teachers find problematic about the use of graphing calculators in mathematics instruction?*" Several issues surfaced that I categorize as problematic when the preservice teachers used graphing calculators in instruction. These issues centered on individual planning, on the appropriate amount of use, and on student reluctance to use graphing calculators.

Time and Materials for Planning

The issues of time required for planning lessons and materials or tools with which to plan and teach were of concern for the preservice teachers but not of the same importance. For Fiona, the major concern was having a better quality graphing calculator to use, and for Hope, the major concern was the time investment with an unfamiliar calculator. (Hope did not have this problem during student teaching, but she was very assertive in her statements regarding this issue.)

Fiona stated her concern about the availability of particular models of graphing calculators:

> in fact I think the reason that I had TI – 81s worked against me. Uhm…they're not nearly as technologically advanced as the 85s. A lot of the things I was planning to do, I automatically assumed I could do, and I couldn't. A lot of things I wanted to do, I couldn't. I wanted them to be able to do when x equals this, punch a key, what does y equal. And go to points specifically on the graph, which you can do on the TI – 85. You cannot do that on the 81s. (Interview 3)

I inferred from Fiona's remarks that she felt hampered by the limitations of the graphing calculator available to her. The implementation of the lessons that she had planned was difficult because she had to constantly circumvent the limitations of the TI – 81 graphing calculator.

The graphing calculator at Hope's disposal was the TI – 83. This calculator was quite familiar to Hope because she had used it throughout her coursework for certification. She emphatically told me that working with an unfamiliar calculator could be a large problem for a mathematics teacher.

> Being comfortable with the calculator—it made my planning quicker. If I wasn't comfortable with it, what I would've done is gone through the activity and learned the calculator as I planned the activity. I may have changed the activity, I'm not sure, it's hard to say. And, also, if I didn't have the time, then I wouldn't have been able, in the real life teaching situation, if I wasn't comfortable with the calculator and I didn't have the time to, I wouldn't have the time to sit down and figure out, I'm pretty sure, I wouldn't be able to do the investigation. So, yes, I think it's important [familiarity with the calculator], and I think you need to learn it before you're in a teaching situation, if possible. (Interview 3)

Fiona expressed similar thoughts about the comfort level or familiarity with a given graphing calculator. (In the remainder of the chapter when reporting interview dialogues, I refer to myself as Researcher and to the participant using the participant's pseudonym.)

Researcher Do you think that comfort level was important in planning the Pre-algebra lessons that used the graphing calculator?

Fiona Very much so. The TRACE[7] mechanism is not good on the 81. If I had it to do over again, I would have pushed, and I probably could have gotten 82s or 83s [TI – 82 or TI – 83 calculator].

Researcher So, the comfort level does play a big part in…

Fiona The comfort level does play a big part. I would have been more comfortable with something I was more familiar with, but even 82s and 83s are going to be closer to an 85 than an 81 was…So, yes, without knowing something about the graphing calculator, it would be much harder. (Interview 3)

A secondary issue was the availability of materials for planning a graphing-calculator approach to mathematics lessons. Fiona related the problem of older texts not having graphing-calculator investigations. Fiona often consulted websites for ideas about a graphing-calculator approach to lessons that she would teach. For the Pre-algebra students that she taught, these resources, (i.e., the Texas

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[7] TRACE is a built-in function on the graphing calculator that reports the x-value and the y-value as the cursor "traces" along a graph.

Instruments website) often did not address lesson plans for the TI - 81 graphing calculator at that level.

> Thinking of things, trying to create things, trying to figure out a different way to teach it. It's not in the books; it's not, you know, especially since I had the 81, there weren't manuals out there. The TI website did not cover 81s very well, especially for pre-algebra. It was hard to come up with things…It was difficult, but that's my job. (Interview 3)

> I did not have enough ideas of my own, and I had a hard time finding ideas appropriate to my student level and calculator type. (E-mail prompt 3)

However, Fiona indicated that further research and more time thinking about content and topics usually were sufficient for her to create activities for her students. On the other hand, Hope was not troubled by this problem at all.

Researcher	How difficult was it for you to develop plans for teaching about lines that actively involved the graphing calculator?
Hope	Not hard at all. I have no trouble with that.
Researcher	Did it take you extra time?
Hope	No, not at all. (Interview 2)

I concluded that Hope found fewer problems with planning because the model of graphing calculator, the TI – 83, that she used was advanced in design and provided many more features with which to plan lessons. Additionally, the curriculum materials with which Hope worked in the Applied Algebra course were calculator-driven, and, therefore, the suggested lessons were more easily adapted to the graphing calculator. (The curriculum materials required only a scientific calculator.)[8]

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[8] A scientific calculator does not necessarily have graphing capabilities; whereas, the graphing calculator does contain the features of a scientific calculator.

Although Hope had few problems thinking of activities or approaches, she still had problems. She described those problems this way:

> Designing the investigations is not an easy task; so that is problematic, too. It's really time consuming to design something that will get them to think, get them to actively do something that is very difficult. I know teachers don't have that much time. You have an hour and a half at most to do your planning. And I spent every night 'til bedtime planning, grading, whatever. I came home, cooked dinner, ate, and my husband did most of the housework. And even with all that, I still didn't get enough planning done, didn't have enough time. So, time is a really big factor in everything—in every investigation. (Interview 3)

The curricular materials with which Hope worked gave her an advantage because she already had ideas for exercises to use with her students. However, the materials did not always promote more thinking by the students because of presentation of the concept. The presentation or design of the activity was Hope's concern. Her beliefs that students learned by discovery and should be critical thinkers caused her to alter the activities so that they were investigations that promoted deeper thinking by her students, and the essence of the problem was the time involved in planning. I recognized that Hope saw the graphing calculator as an aid for developing critical thinking skills, and her "effective tool for learning" belief about the calculator was a derivative (Green, 1971) of the "critical thinker" belief.

The issues of adequate time for planning and of an adequate calculator for teaching raised my awareness of the preservice teachers' concerns about proper preparation and proper tools for teaching. These concerns were directly related to the preservice teachers' belief that their purpose in teaching was to create an environment for learning and an environment for success of their students. They were concerned about each individual student's learning as well as the learning of the class as a whole. The responsibility that they felt for the students' learning was quite evident in our conversations. In Hope's case, she wanted time to plan for optimum learning, and, in Fiona's case, she wanted a calculator that provided ways to facilitate the new approaches to the content she was teaching.

Fuller and Bown (1975) stated that preservice teachers react to the classroom situations around them in a series of stages. The concerns of both Hope and Fiona progressed through the third stage described by Fuller and Bown and the four areas of concern identified by Schwab (1973). In the third stage of concern, preservice teachers examine student learning in terms of teacher actions and how those teacher actions interact with learning. Each preservice teacher expressed concern for the effect of her teaching actions on student learning. One example of Hope's concern is shown below. From Hope's statements, I deduced that she felt responsible for the mathematical relationships learned by her students because of the strategies and tools Hope could use to teach those concepts. Her "calculator as a tool for investigation" belief was a derivative (Green, 1971; Rokeach, 1960) of the "seeing relationships" belief because of the impact the calculator made on the visual relationships of the concepts. In this instance, I concluded that Hope thought her students would have formed a stronger connection between the *y*-intercept and its function had she allowed them to discover relationships of the concept through an expanded activity rather than receiving the information from the teacher.

Researcher You told me you used the calculator to show students the difference between slope and the *y*-intercept. Did the students make the connection that the *y*-intercept only locates the line on the *y*-axis?

Hope No. I don't think so. No. And that's partially a me-learning-how-to-be-a-teacher problem. It's allowing them to discover things. I'm not there yet. And that's just going to take some time and practice. It's not the calculator's fault. (Interview 2)

During an observation of Fiona's class, she was reviewing answers to a test that she had given previously. After conferring with neighbors, some of the students questioned the grading of a particular item on the test. (Fiona had marked two different answers correct on two students' papers.) To explain this phenomenon Fiona said, "When I read the test question again, I realized that there were two interpretations for what I had written. So, I gave credit for the correct answer for each interpretation. Next time I will word the question better." I heard comments of "Cool!" from the students because Fiona saw her mistake in phrasing the question as she did and did not penalize the students for having a different interpretation of the test question than she had intended. This action was also an example of "validating the opinions of all students" that she spoke of in the mathematics autobiography. I saw the action as a direct effort to encourage students to be critical thinkers, a belief Fiona had stressed in many other statements.

Appropriate Amount of Use

A further issue related to problematic situations developed from the preservice teachers' inability to reconcile the amount of calculator use in the classroom with what they saw as disadvantages in future contexts. Both preservice teachers wanted to use the calculator, and both thought the calculator had many benefits for students. Hope said that her fear was "they'll rely on the calculator too much. And, that when they get to the test, without the calculator, they won't be able to do the problem." Fiona had similar unresolved thoughts about calculator use. She said, "Probably the same reservations, the big argument that everyone has, if they're using the calculator, do they really know the math? Can they do it with pencil and paper?" Simonsen and Dick (1997) and Zand and Crowe (1997) reported the same fears and attitudes from teachers in their studies regarding calculator use and computational skill. The fear that students will lose computational skill is contrary to what other research studies have shown, however. For example, Heid (1997) found that students who used calculators had no loss in computational skills, and, in fact, the students' computational skills were enhanced by calculator use. Thus, my data showed that the fears and attitudes of my participants matched the fears and attitudes of other inservice teachers that have been studied by other researchers, even though existing research has told us that calculator use is not detrimental to students' computational skills.

I concluded that the quandary of my preservice teachers concerning the amount of calculator use in the mathematics classroom and erosion of computational skills was a product of their shared beliefs that the study of mathematics is a sense-making activity and that one purpose of the mathematics teacher is to create a learning environment for success of her students. As I saw it, a conflict existed between the two beliefs because of the strength with which the beliefs were held by the preservice teachers (Green, 1971; Rokeach, 1960). On the one hand, the calculator is an effective, instructional tool to aid students in making sense of mathematics; on the other hand, the prohibition of calculator use in certain testing contexts might limit the success of their students if the students became dependent on the calculator for computation.

Student Resistance

Reforming the teaching of mathematics has been a problematic task, and the task is not complete. One of the major roadblocks to reform is getting teachers to "buy into" reform, (i.e., specific methods of teaching or tools for teaching). Part of teachers' reluctance to implement reforms in the classroom stems from student resistance to these reforms. Heid (1997) and Griffith (1998) reported that students were slow to cooperate with teachers attempting to use reform components in their classrooms. The researchers called this reluctance *student resistance*. For this study, my definition for *student resistance* is the reluctance of the secondary student to use the graphing calculator, even though the calculator can benefit the student. Likewise, Fiona and Hope experienced the same difficulties when attempting to use the graphing calculator, a tool of reform in mathematics instruction.

Hope related that she had taught the Applied Algebra classes how to use regression on a set of points, and the students really "got into that." On another day, however, she worked with two points on a line with the goal of finding the slope of that line from the given points. Hope told the class that they could find the slope of the line between the two points using regression on the calculator. She reported:

> And I thought about doing regression with the points to find the slope, but I didn't and I'm not sure why. I might should have and I may later. It was just so much; they were having a real hard time with the concepts, and I didn't have that much time left. And, they weren't getting it. And I asked them, I actually asked them, I said, "Do you want to know how you can get the calculator to help you find the slope when you have two points?" And they said no. So, I didn't go there. I guess that's why I didn't do it. (Interview 2)

Although I did not observe this lesson, I inferred from Hope's remarks in the interview that her students were overwhelmed by the concept of finding the slope of a line from two given points on that line. The strong reluctance that Hope's students displayed in this instance discouraged her use of the calculator because "it was just one more thing on top of everything else."

I labeled this event student resistance. Hope and Fiona experienced this phenomenon in their classrooms during student teaching. I discovered as I talked more with the preservice teachers that there were several factors that they identified that contributed to student resistance. Both preservice teachers cited the attitudes of elementary teachers as a major contributing factor. Hope commented:

> I do know that some teachers, especially elementary teachers, discourage the use of calculators. I've heard that a lot, even like yesterday, Allen (pseudonym), the boy that stayed for help today, his teachers have discouraged him from using calculators. His mother said he'd been discouraged from using the calculator, and he doesn't really want to use it now. They tell them, "It will make you lazy. It'll make you not be able to know your facts." The teachers tell them things like this. I think the elementary school teachers are most of the problem. (Interview 2)

Another contributing factor was student apathy. At times Hope found, "They just don't care! The calculator is there to help them, and they won't pick it up and use it. I really don't understand their attitude." Fiona had similar problems in her Pre-algebra class. Her overall objective for using the graphing calculator was to find new approaches to teaching Pre-algebra so that her students could be successful in the course. I viewed this belief about the technology as a tool for aiding in success as a derivative (Green, 1971; Rokeach, 1960) of the "classroom environment" belief about teaching. However, she also experienced a kind of apathy from her students; she said:

> They've been taught this stuff for years; so, they've been taught it different ways. And, here's another teacher teaching it another way. So, I don't know if they just—sometimes I feel like they're getting fed up. They almost understand what's going on, and they'll say, "I learned it that way." And it's like, "Yeah, but we're doing it this way." And it's hard to incorporate all their different ways at once, especially if the way they think they're doing it is right and it's not. (Interview 2)

In her class, Fiona experienced a unique situation related to student resistance. She labeled a male student, Jake (pseudonym) in the Pre-algebra class as "a ring leader" because a subgroup of about five males in the class tended to follow Jake's lead. Jake constantly mumbled derogatory remarks about using the calculator, "[He]'d rather do it the old way—with my pencil and paper," even though he was not very successful "the old way." Jake's attitude was that he was too "macho" to use the calculator, and "The calculators are just stupid."

Unfortunately, a small group of the male students in the Pre-algebra class listened to his comments and did themselves a disservice. When Jake was absent from class, this element of student resistance disappeared. Fiona noticed some of the males in the subgroup actually used the calculator to help them in their study of mathematics.

> Kayla loved it! Kayla used that TEST[9] function on everything we did after I taught her how to use the TEST function; she LOVED it. And, even Rick (pseudonym for one male in the subgroup), I caught using the TEST function. (Interview 3)

Kayla was a counterexample of the student resistance issue. At the beginning when Fiona first introduced the calculator, Kayla resisted using the calculator. However, Kayla's attitude changed dramatically after she saw what the calculator could do for her in the mathematics classroom.

I inferred that both preservice teachers were frustrated with student attitudes about using the graphing calculator because the preservice teachers shared the belief that one purpose of the teacher is to create an environment that promotes the success of her students. The teachers recognized the graphing calculator as a tool that could help their students succeed, and, yet, the students, at various times, chose not to use the calculator and to succeed.

Uses of Graphing Calculators

The second research question that guided this study was, "*What factors influence the use of graphing calculators in mathematics instruction?*" The factors that influence the use of graphing calculators can be characterized as both positive and

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[9] TEST is a built-in function on the TI-81 calculator that reports whether the inequality value for a given inequality will make the statement TRUE or FALSE.

negative: those influences that encourage graphing calculator use and those influences that do not. I assumed that the preservice teachers' beliefs about teaching, about learning, about mathematics, about students, and about technology would play a major role in their choices to use graphing calculators in mathematics instruction. These beliefs contribute to a significant part of the teachers' philosophies about mathematics and mathematics education and which teacher actions that they use in mathematics instruction (Simmt, 1997). Based on that assumption and the categories of use reported in Simmt's research, I looked at the categories of graphing calculator use by the preservice secondary mathematics teachers in my study and which beliefs influenced that use.

In Simmt's study (1997), the participants were six inservice teachers who were teaching transformations of the quadratic function. Although the teachers had the same availability to graphing calculators and the same curricular requirements for the unit, the categories of use of the graphing calculators were quite different. The categories of use that Simmt found in her study considered the graphing calculator a tool for: 1) checking work, 2) plotting graphs of functions, 3) finding graphical solutions, 4) understanding word problems, 5) exploring beyond the concept being taught, and 6) providing a picture. Analyzing Simmt's uses, I collapsed uses two, three, and six into *finding graphical solutions*, and I inserted two new uses: *tool for simulating real-world phenomena* and *tool for motivation.* I found only one example for one of my participants of *tool for understanding word problems* that I addressed when I used that example for illustrating another use.

The preservice teachers' use of the graphing calculator fell into several categories. In Figure 6, I summarize the categories for each preservice teacher. (For the category *Tool for exploring deeper, richer mathematics,* "richer" is the term I chose to describe my thinking about mathematics that was previously inaccessible when computing by hand.)

Use of graphing calculator	**Fiona**	**Hope**
Tool for checking work	yes	yes
Tool for finding graphical solutions	yes	yes
Tool for exploring deeper, richer mathematics	no	yes
Tool for generating alternate solutions	yes	yes
Tool for simulating real-world phenomena	no	yes
Tool for visualization	yes	yes
Tool for motivation	yes	yes

Figure 5: Graphing calculator uses

Tool for Checking Work

The impetus for using the graphing calculator as a tool for checking work that has been done by hand was a derivative (Green, 1971; Rokeach, 1960) of the preservice teachers' shared belief about classroom environment. During the first observation of Fiona's class, her plans were clearly based on getting students proficient enough to check answers resulting from algebraic manipulations, independently, with the use of the calculator. Fiona said to her students, "If we know how to use our calculators, we'll always have correct answers."

This type of activity also demonstrated Fiona's belief that students should not see the teacher as the only authority for "the right answer." Because students could convince themselves, without asking the teacher, that the solution at which they had arrived was correct, this calculator confirmation of the correct answer empowered the students about the correctness of their solution methods, thus shifting the authority for "the right answer" from the teacher to themselves as the operators of the graphing calculator. This "calculator as authority" belief was a derivative of the "authority shift" belief about students. Fiona related her reasons for using the calculator to check work:

> I wanted to give them confidence, and I also thought if they used it [the calculator] they could check their answers right away. They would know if they're doing it right or wrong. I would no longer be the sole authority. They would be able to do something, check it—yes, I have it right; yes, I have it wrong; what am I doing wrong? (Interview 2)

This statement underscored Fiona's belief that a teacher should provide as many tools as possible to promote an environment for success of her students.

In an observation of Hope's class, students worked on finding the slope of lines. At one point Hope said, "Everyone should get the same answer. Use your calculator if you're not sure about the division." During the second interview, Hope told me she always encouraged her students to use the calculator if they were unsure of their arithmetic facts; she said, "That's why [she] convinced [her] mentor teacher to leave the calculators out on the tables at all times."

Hope thought that the calculator was a powerful tool for students because of the three representations immediately available on the calculator. She said, "They can see the three representations: the equation, the graph, and the table. All from one place in the calculator." These three representations available in one place helped students see the relationships among the elements of mathematics: the symbolic, the visual, and the computational. Thus, the primary belief (Green, 1971) that students should see relationships while learning mathematics was addressed by this capability of the calculator as students checked graphing exercises.

Fiona's conception of how to use the graphing calculator in her Pre-algebra class was based on her derivative belief (Green, 1971; Rokeach, 1960) that a teacher should provide as many tools as possible to promote an environment for success of her students. At the beginning of student teaching, this conception was that enabling students to check their work via the graphing calculator would give the students confidence in their mathematical abilities and show them other ways, besides the teacher, to validate their work. This approach for teaching Pre-algebra was new to the mathematics department in the school in which Fiona did her student teaching.

The approach was so new and different that Fiona sensed undercurrents of negativity about the success of the approach.

> Mrs. Boggs[10] encourages me to try new things. I don't think that she felt that this [checking inequalities with TEST] would help. She is not as pro-calculator use as I am, and that shows up in this class a lot. (Interview 2)

In the third interview, Fiona actually enumerated several sources of negativity:

> …if I had my own classroom, if I had the support of the department, and if everyone didn't think I was crazy for using calculators in a Pre-algebra class of this sort! (Interview 3)

Had the preservice teacher been less strong-willed and less determined to reach her students with this new approach, I concluded that this negativity could have severely hampered her efforts of a preservice teacher. I deduced that Fiona's belief that one purpose of the teacher is to provide an environment for the success of her students was the driving force (Thompson, 1984) in the implementation of this approach. The success of the approach was evident in the results. The class average for the test Fiona gave on this material was 75; the administration later told Fiona that 70 percent of the students in her class were expected to fail the Pre-algebra course. This number of failing students was very unacceptable to Fiona. "I cannot imagine that number failing without questioning what I'm doing as a teacher!"

The situation Hope faced was very different. Her mentor teacher, Mrs. Tree[11], urged Hope to use the calculator whenever feasible. The curriculum

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[10] Mrs. Boggs is the pseudonym for Fiona's mentor teacher.

[11] Mrs. Tree is the pseudonym for Hope's mentor teacher.

materials that they used for the Applied Algebra course were calculator-driven, which meant that the use of the calculator was required; however, the specified calculator was a scientific calculator rather than the graphing calculator that Hope used with her applied classes. The graphing calculator is a scientific calculator with graphing capabilities and, also, other capabilities the scientific calculator does not have. Therefore, the factors that might have discouraged Hope's use of the calculator were different from those that might have discouraged Fiona.

During an observation in Hope's Algebra I course, the graphing calculator was used to verify the work students did to factor trinomials. Hope instructed the class to graph several trinomials, one at a time, on the graphing calculator, and, for each trinomial graphed, a student was chosen to operate the computer program called *MAPLE*. (This program reported the factors of the trinomial.) Hope led the class, through a series of questions to different students in the class, to conclude that the factors of the trinomial were always found on the x-axis with the opposite sign value from the actual factor (I observed that not all students understood this concept, however.). Thus, in the exercises for factoring trinomials that followed the first activity, students were asked to use the graphing calculator to check their work by reading the resulting graph. As the activity progressed, some students would not use the calculators. I heard Hope tell one or two students, "Fill in the rest of the exercises; there are 2 points where it crosses." And another student said, "I do not like this!" I labeled this event student resistance. In this instance, Hope overcame the discouragement the student resistance posed because of her belief that the graphing calculator provided a clear, visual picture of the concept that she wanted her students to learn. I viewed this belief as a derivative (Green, 1971; Rokeach, 1960) of Hope's content-focused approach to teaching mathematics.

I concluded that Hope anticipated the student resistance that we observed during this class period. To overcome the student resistance, she planned her lesson activity to actively involve the graphing calculator in factoring trinomials by using the visual graphs to verify the correct factored form. The activity included thought-provoking questions that required use of the graphing calculator to extend the thinking of her students in order to answer these questions.

Tool for Finding Graphical Solutions

Near the end of student teaching in the third observation of Fiona, her class of Pre-algebra students worked on solving two-step equations. Two-step equations involve solutions of two different processes. For example, an equation of this type that Fiona's students solved was $2x + 5 = 11$. To solve this equation, Fiona's students first subtracted 5 from both sides of the equation to keep the balance on each side of the equation. Then, the students divided each side of the equation by 2. As I observed this class period, the students had random success with the solutions to the exercises. Fiona had another plan, based on earlier activities where the class had solved simple one-step equations using the graphing calculator.

Fiona	We can solve this on the calculator. What do we do?
Student 1	Put 11 in Y1.
Fiona	Good. I want to do this with graphing. I think it will make it easier. Now, what?
Student 2	Put $2x + 5$ in Y2 and graph it.
Fiona	Yes. GRAPH. Where the two graphs intersect should be the algebraic solution. (Observation 3)

The students used a built-in function of the calculator, TRACE, to obtain the actual value for the variable x.

Fiona used the graphing calculator to teach solving two-step equations with a new approach: graphing two lines and looking at the intersection of the lines. I concluded that her use of the graphing calculator in this way was the result of her belief that the graphing calculator provided a clear, visual picture of the problem. This use was also an example of her beliefs about students and about learning: students should be critical thinkers and students should understand and use the relationships in mathematics. Thus, Fiona's "calculator as a visual tool" belief was a derivative (Green, 1971; Rokeach, 1960) of the two beliefs "critical thinkers" and "seeing relationships."

A similar situation developed in Hope's class of Applied Algebra. The goal of the day's lesson was solving equations that used the distributive property for simplifying the variable side of the equation. One equation used in class that day was $2x + 3 - 5(x + 4) = 1$. The symbolic manipulation method for solving the equation involves multiplying -5 and $x + 4$ and combining variable terms and constant terms of the variable side (left side) of the equation. The result is $-3x - 17 = 1$. This equation becomes a two-step equation similar to the one discussed earlier (In this example, one adds 17 to both sides of the equation, and then divides both sides by -3.). Hope used the graphing calculator in the same way that Fiona had in her class. Students put the left side of the equation, $2x + 3 - 5(x + 4)$, in Y1, and the right side of the equation, 1, in Y2. After pressing the GRAPH key and getting two lines, they looked at the intersection to find the algebraic solution. When I asked her about this lesson later, Hope said:

> When you can turn a math problem into a picture, like, for me, you know, that's how I solve problems. If I can make a picture, I can solve it. And a lot of my students are the same way. They solve the problem by looking at the graphs. (Interview 2)

The cluster of beliefs (Green, 1971) illustrated by Hope's use of the graphing calculator in this instance reflected beliefs about graphing calculator technology, beliefs about students, and beliefs about learning mathematics, (i.e., the effective visual component of the calculator, the critical thinking of students, and the student's understanding and use of relationships in mathematics). I concluded that the psychological strength (Green, 1971; Rokeach, 1960) of these beliefs was the driving force (Thompson, 1984) in the implementation of this use of the graphing calculator.

Hope related another instance of students using graphs to solve a problem in the Applied Algebra class. The class was studying acceleration and velocity. In this particular problem, the students were given an expression for the acceleration of an object (a quadratic) and a period when the object had a constant velocity (a straight line). The question was, "Were they [acceleration and velocity] ever at the same place at the same time?" Hope's students promptly put one expression in Y1 and the second in Y2 and looked at the graphs. This example was also an illustration for a use Simmt (1997) found in her study: *tool for understanding word problems.* This instance was a unique occurrence in my data. Hope further explained:

> They could look at that graph and say, "Yeah!" They thought it was a stupid question. You know, it was right there. But, I said, "Could you use these equations and solve it?" They had no clue what I was talking about. There would have been no way. Visualization! I think it's very important. (Interview 2)

Again, Hope demonstrated her beliefs about the calculator as an effective learning tool because of the visualization component, about students as critical thinkers, and about understanding and using relationships in mathematics.

Upon further examination, I recognized this example as disconfirming evidence of Hope's belief that students should know how to compute problems by hand. On several occasions, she voiced fears that using the calculator could cause students' computational skills to erode. However, in this instance, she admitted that, without the calculator, her students would have been unable to devise a solution to the problem. In light of this instance of disconfirming evidence and others for the "compute problems by hand" belief, I characterized this belief as peripheral or having less psychological strength than those about calculator use (Green, 1971; Rokeach, 1960).

Both preservice teachers cited instances when graphing approaches to problems caused trouble spots with the students. At one point on the graph, the solution should have been zero, but the calculator did not report zero. Fiona said:

> We got our answer as -.06 x 10 to the –2 million. It was zero. But the calculator would not call it zero. It was a tolerance issue. It wasn't something I was planning on dealing with. They [students] don't—we did scientific notation. So, I've just spent all this time telling them that this is a number, and I have to turn around and tell them it's actually zero because of the tolerance. It was hard for me to make that connection and that point at that time with those students. They wanted a cutoff—if it's here, it's zero, and beyond there it's a number. (Interview 3)

I inferred from Fiona's remarks that the students found the tolerance issue hard to understand because it contradicted what they had learned when they studied scientific notation. At another time during an observation of the Pre-algebra class, they used the TRACE key to search for ordered pairs, and the TRACE outputs did not match. Fiona said:

> Sometimes with the TRACE key, you were there that day; my TRACEs didn't match their TRACEs. I did not know if I could set the TI – 81s to change that or if that would not have been a problem with another calculator. I don't know. That's something I would have to check into. It was problematic. They [students] thought something was wrong with the calculators. (Interview 3)

I concluded that Fiona realized this type of event could lessen the value of the calculator in the eyes of the students. Moreover, if such events were too prevalent, student resistance could become even stronger related to graphing calculator use.

Hope related examples where data for the calculator did not fit the relationship that the class was studying. In these cases, she attempted to explain why the calculator treated random data points as it did. I concluded that both preservice teachers saw these events as troublesome because instruction time was devoted to unplanned explanations. The unplanned explanations decreased time from other planned activities, and this situation was problematic for both preservice teachers, even though Hope conceded that "it was something in mathematics we could talk about." Moreover, because these events were troublesome to the preservice teachers, this type of event might serve to deter their use of the graphing calculator.

Tool for Exploring Deeper, Richer Mathematics

This use of the graphing calculator was recognized exclusively by Hope. Several observations prompted this conclusion. From the beginning of student teaching and throughout the ten-week period, Fiona thought that her Pre-algebra students' use of the calculator would be "procedural." When I asked her to elaborate on this term, she said, "Type something in and get an answer." Only after student teaching ended, did Fiona realize that her Pre-algebra students could and did generate alternate solutions and explore mathematical concepts, higher levels of graphing calculator use than "procedural."

> Because at the end, they were exploring the change in y and change in x, and they were conceptualizing. And I said it would all be procedure—it would all be punching in numbers and getting an answer. But it wasn't, they were exploring with it [the calculator] even though they didn't know it and I didn't know it. They were, weren't they?…and I didn't think that would happen. (Interview 3)

Hope, on the other hand, used the calculator to do richer mathematics with her students on at least two occasions. Early on in student teaching, she showed her Applied Algebra students linear regression on the calculator. *Linear regression* is a process that fits a set of points to a line, using "best-fit" properties and calculations to find the line. This topic is not usually addressed in the high school curriculum, especially with lower-level algebra students. Nevertheless, with the graphing calculator, Hope's students "got into it" because the functions of the calculator gave the students success with these types of mathematics problems. Hope reported to me that the regression problem on her first test was "one they got correct most of the time. Very few people missed it!"

During the fourth observation of Hope, one of the goals of her lesson was to give students practice with reporting common statistical measures of sets of data, (e.g., mean, median, mode, range, and standard deviation). Although the mean, median, mode, and range are calculations found in elementary school mathematics, the standard deviation is not a simple calculation even for secondary students. However, with the calculator, Hope's Applied Algebra students learned how to input the data so that the calculator could do these messy algorithms for them. They then interpreted what the data were and what the statistical measures meant in terms of the context of the problem that they solved using the calculator this way. Hope wanted her class to have a clear understanding of the statistical concepts because this knowledge could help them succeed in life.

I recognized this activity as evidence of Hope's beliefs that all students can do many levels of mathematics given proper tools to help them, that students should be critical thinkers, that teachers should provide as many tools as possible for the success of her students, and that students learn mathematics through real-world applications. Thus, Hope's belief about the calculator as an aid for doing many levels of mathematics was connected to several psychologically strong beliefs about students, about mathematics teaching, and about mathematics learning (Green, 1971; Rokeach, 1960, 1968).

Tool for Generating Alternate Solutions

One of the last lessons that Fiona taught was how to construct a T-table for a given linear equation. A *T-table* is a set of y-values generated by x-values substituted into an equation, (e. g., $y = 2x$). Her students were familiar with this concept, and she planned to use the graphing calculator to generate one of the two pairs required in the assignment. The instructions to her students were:

> Use the equation, choose an x-value, and find the corresponding y-value by substitution. Then put the equation in the calculator and graph it. Use the TRACE key until you find another pair on the line. And, let's use whole number pairs. That way, you've found one pair using algebra and one pair using the graphing calculator. (Observation 4)

I concluded that this activity was an illustration of Fiona's beliefs that the calculator is an effective tool for learning, that students learn mathematics through discovery, that the teacher is not the sole authority in the classroom, that students should be critical thinkers, and that students should know how to compute problems by hand. Thus, as I reported earlier with Hope, Fiona's belief about the calculator as an effective tool for learning was connected to several psychologically strong beliefs about students, about mathematics teaching, and about mathematics learning (Green, 1971; Rokeach, 1960, 1968). The striking difference was Fiona's resistance to totally depend on calculator-generated solutions for the T-table exercises. I viewed this action as evidence that the "compute problems by hand" belief was psychologically central in her belief system (Green, 1971; Rokeach, 1960).

During the observation of Hope's Algebra I class in which the students were factoring trinomials, Hope used both the computer and the graphing calculator. The purpose of using the computer program *MAPLE* was reporting the two factors of the trinomial, whereas one purpose of using the graphing calculator was to generate the zero values of the trinomial by reading the values from the graph displayed by the calculator. Generating the zero values clued the students to the actual factors of the trinomial if the traditional factoring methods failed to give the correct factors of the trinomial. Hope prompted the students' understanding by asking these questions, "Is everybody getting a graph? What are the two points where it crosses [the x-axis]? What do you think happens here?"

It was interesting to both Hope and myself that one student found another method all on her own to generate a checking solution when factoring the trinomials. This student found what she believed to be the two factors of the trinomial. Then she typed the original trinomial into Y1, and her factored form, the two factors multiplying each other, she typed into Y2. She pressed the GRAPH key and looked at the graph displayed on the screen. If she had exactly one graph on her calculator, she knew the factored form that she used in Y2 was correct. This new method of checking the factoring showed a strong grasp of the concept of factoring trinomials. Hope was very excited about the knowledge displayed by this student. She shared this original method with her mentor teacher; however, she did not ask the student to share the method with the class.

I recognized this activity as evidence of Hope's beliefs that the calculator gives a clear, visual picture of the mathematics, that students should understand relationships in mathematics and use those relationships to solve problems, and that learning mathematics is a sense-making activity through discovery.

Tool for Simulating Real-world Phenomena

A use of the calculator not reported in Simmt's study (1997) that Hope quite successfully incorporated into her teaching was as a tool for simulations. I attributed this new use to the circumstances in the activities of the day's lesson as well as the circumstances of Simmt's study. The particular activity in Hope's lesson called for a manipulative (a single die for each student) that was unavailable to Hope. Therefore, she used the calculator to simulate the use of the die as specified in the activity. The circumstances of Simmt's study focused on a particular unit. This unit was on the transformations of quadratic functions, and I suspected that there was no need for each student to roll a single die in the exercises and activities specified in the unit on the quadratic function.

The day I observed this class, Hope's objective was to demonstrate applications of probability and the ease with which these applications could be evaluated using the calculator. She had her students to look at problems ranging from contexts for permutations to the expected frequency of a sum obtained from rolling a pair of dice. It was this last activity that prompted the simulation use of the graphing calculator. In this activity, the students were to pair off to model a pair of dice. Each student then "rolled a die" and recorded the result of that roll in a table of twelve entries. Because the manipulatives were unavailable to Hope, she instructed her students to use the graphing calculator to simulate "rolling a die."

> Because we don't have a die for each of you today, we can get the calculator to simulate rolling a die. Tell the calculator how to simulate a die roll by using the built-in random number generator that gives numbers from 0 to 1. But we want 1 to 6. Go to the MATH menu and choose number 5 for probability. Type in INT (6 * MATH Prb 1) + 1."   (Observation 5)

To complete the activity, the students summed the rolls for each entry in their tables and plotted a frequency histogram of the sums for the data obtained from all the student pairs in the class. These data led to a class discussion about the sums and their frequencies.

I recognized this use of the calculator as evidence of Hope's beliefs that one purpose of the teacher is to create an environment that promotes the success of her students, that the graphing calculator is an effective tool for instruction, and that activities should help students make sense of mathematics. Without the calculator to simulate the roll of a die, Hope's students would have been unable to complete the activity and discuss why certain sums occurred more frequently than others did when rolling a pair of dice. Therefore, the “effective tool for learning” belief about the calculator was a derivative (Green, 1971; Rokeach, 1960) of the “classroom environment” belief.

Tool for Visualization

Although Simmt (1997) listed this use of the calculator separately, my data suggested that this use of the calculator should be subsumed under the use “Tool for Finding Graphical Solutions.” I made this conclusion based on the fact that even though I had many more examples to support this claim about the use of graphing calculators regarding visualization, the other examples did not speak to a different point about visualization.

Hope did point out a disadvantage related to the visual component of the graphing calculator. When other technologies such as computer software are used to graph functions, each new function can be graphed in a different color. The graphing calculator does not have this capability, and Hope thought that having several graphs on the same screen with no way to tell them apart could be confusing to the calculator user. I concluded that, though this visual component can be confusing, Hope still persisted in her use of the graphing calculator because of her belief that the graphing calculator is an effective tool for instruction.

Tool for Motivation

The use of the graphing calculator as a tool for motivation presented a two-sided benefit: one for student motivation and one for teacher motivation. The factor of motivation affected student behavior toward learning, and it affected the preservice teachers’ creativity in planning of lessons.

Before Fiona's class on T-tables, I observed students getting calculators from the storage boxes as they entered the classroom, opening cases, and playing with different features on the calculator before the lesson began.

Researcher	I noticed, during the last observation, the students seemed more eager to use the calculators. Do you agree?
Fiona	Yes.
Researcher	To what do you attribute this phenomenon?
Fiona	They were probably to the point of realizing that I was not going to give up this calculator thing. I was going to use it , and I think I was doing something that animated, you know, and I think they finally realized we're going to have to use these. So, let's listen to her for a minute. I was animating—I was taking any answer they got. It didn't—it wasn't one correct answer. I think they liked the fact that I gave them different ways to solve these problems—do it algebraically, do it with a graph, give me any two points, I don't care which two. (Interview 3)

Fiona's students had realized that she intended to use the calculator, but I perceived that the students were eager to see how they would use the calculator in that day's lesson. The classroom had an atmosphere of excitement that I attributed to the students' anticipation of the mathematical activities in which they would engage using the graphing calculator. I attributed Fiona's perseverance in planning for and implementing the use of the graphing calculator to her belief that the calculator is an effective tool for instruction, a derivative belief (Green, 1971; Rokeach, 1960) of the "many tools for success" belief.

Hope saw an even stronger influence of the calculator in her classes because she tended to use the calculators on a more regular basis. In fact, she told me her use was probably 25 percent of the time, and this percent could be related to a weekly use; of course, some days the time was much longer than on other days. She related the motivational factor in this way:

> The calculator is actually a tool to get them to pay attention. For me, I'd say, "OK, everybody get your calculators out." And, everybody's doing something: they're getting the calculators out, they're opening them, they're turning them on, and, then, I can give them things to do—steps to follow—it focuses them. I always liked when we were doing calculator activities. I knew that I could get their attention. (Interview 3)

From this description of student behavior, I concluded that Hope's students viewed the use of the graphing calculator as a positive addition to the methods and tools for mathematics instruction. In most cases, they were receptive to the activities designed to use the graphing calculator, and Hope's continued and sustained use of the graphing calculator underscored her belief that the calculator is an effective tool for learning.

The other side of the motivation factor was manifested in the planning of the preservice teachers. Fiona, in particular, said that planning activities that used the graphing calculator forced her to be more creative.

> I had a goal in mind. So, it gave me something else to work with. If I hadn't been looking at the graphing calculators, my lessons probably would have been worse because I probably would have just fallen back on standing up there and telling them what to do. So, the graphing calculator might have pushed me a little harder—it was more in the thinking process, the commuting and thinking, "What can I do?" not the actual writing or anything like that. The actual teaching of it, I don't think, was any harder. I think it took a little longer, more creativity to come up with a different approach. But I think it was worth it. (Interview 2)

When I observed Fiona's classes, the mathematical discourse fostered by the use of the graphing calculator was fascinating. Students worked with each other, though not in an organized group other than the class itself; and, of course, students worked with Fiona. Fiona told me, at one point, that small groups did not function well with her Pre-algebra students.

Some of the classes I observed had a lecture-style format, but others were very open where students were sharing ideas among themselves. I recognized this environment as evidence of Fiona's beliefs that the teacher should create a learning environment that promotes the success of her students and that learning mathematics is a vehicle for learning about life and how to function in it.

Hope worked in a different situation when planning lessons for her Applied Algebra students. The curricular materials were calculator-driven, and I suspected this aspect made planning easier for Hope. However, Hope stated:

> I think the graphing calculator allowed my lesson plans to create "deeper" mathematical lessons. The calculator allows those who cannot compute (myself included) a glimpse into the deeper side of mathematics. (Personal communication, 9/30/01)

I concluded that Hope was motivated to explore "deeper" mathematics with her students because the graphing calculator was so facile in handling these levels of mathematics. This ability to explore deeper mathematics illustrated Hope's beliefs that the graphing calculator is an effective tool for instruction, that students are able to do all levels of mathematics given proper tools, and that learning should be tied to real-world applications.

Mathematics and Graphing Calculators

The third research question that guided this study was, "*When do preservice secondary mathematics teachers use graphing calculators in instruction during student teaching? If they do not use graphing calculators, do they make a deliberate choice not to do so? If so, what are the reasons for those choices? If the choice is not deliberate, what factors is the student teacher considering when planning instruction?*" Student teaching is the field experience in which preservice secondary mathematics teachers actually "take control" of the classroom. By "take control," I mean choosing how lessons are taught—what activities are used, what strategies are used, and what tools are best suited to aid in mathematics instruction. I answered how graphing calculators were used in mathematics instruction by two preservice secondary mathematics teachers in the second research question. Therefore, the third research question addresses *when*, (i.e., with what mathematics) was the graphing calculator used. I formulated the structure of this analysis by examining content. For my two preservice secondary mathematics teachers, the content was composed of computation and algebra.

Computation

Computation, according to the Random House Dictionary (1971) of the English Language, is 1) the act, process, or method of computing, 2) the result of computing, or 3) the amount of computing. Computation, in terms of content, is the act, process, or method of computing. My focus for investigation was the methods of computing, specifically the types of methods, that I observed in the teaching practices of two preservice teachers. In types of methods, I included arithmetic operations computing, statistical computing, probabilistic computing, evaluative computing, and trigonometric computing.

During the first observation of Fiona, her students used the graphing calculator to verify solutions for inequalities done by hand, using the TEST function of the calculator. The TEST function evaluates a given inequality at a value for x, and reports if the value makes the inequality *true* or *false.* I labeled this instance as evaluative computation. This use of the graphing calculator was an integral part of the lesson plan for that day.

> I think that the calculators will always help these kids. I think these kids need reinforcement. They need to be able—they need to have more than just me telling them whether they are right or whether they are wrong. This [the graphing calculator] is something they can control to tell them they are right or they are wrong. Another avenue for answers. It makes them think more about the answer because they don't just get the answer $y = 7$ or $y > 7$. They need to know what that means because if y has to be greater than 7, they have to think about the other numbers. So, they have to think about that whole inequality and what they are really talking about. (Interview 2)

I concluded that Fiona's "authority shift" belief and the "critical thinkers" belief were the driving forces (Thompson, 1984) in the deliberate use of the calculator for that lesson. These beliefs promoted the use of evaluative computation to accomplish the authority shift that worked to build students' mathematical confidence in their work and to create more critical thinkers.

Throughout my observations of Fiona, she continually encouraged her students to use the calculator to check their arithmetic; thus, she employed the calculator in arithmetic operations computing.

> They should know their basic arithmetic facts by 5th grade. That would be great, but it doesn't happen, though. In the real world when it doesn't happen, we need to try something else. (Interview 1)

This non-deliberate use directly related to the "classroom environment" belief and the "many tools for success" belief that Fiona discussed frequently in our conversations. Making the calculator available for and encouraging its use in arithmetic operations computing validated these beliefs, but no evidence was available that she actually planned for this method of computing.

One of the units that Fiona taught during student teaching was fractions. This unit required the conceptual understanding of what a fraction is as well as the common arithmetic operations with fractions, along with everyday applications of the concept. The graphing calculator Fiona used had features to help correctly evaluate operations with fractions; however, Fiona did not use the calculator for the fraction unit.

> We are currently doing fractions, and there are calculators, like the TI – 34, that do fractions. The TI – 81 will do fractions, if I taught them how to do it. She [Fiona's mentor teacher] doesn't want them doing fractions on the calculators. So, we're doing them long-hand. I'm letting them use the calculators to multiply and divide, but they are NOT using the fraction functions. They don't know where they are, and I'm not going to tell them. That is not my choice. (Interview 2)

Fiona was frustrated by this restriction on calculator use because the restriction conflicted with her "many tools for success" belief. When I asked her why Mrs. Boggs restricted the calculators on fractions, she said:

> It's a departmental choice; it's not simply Mrs. Boggs. I think it's just everyone agrees on what they're going to do, basically, because if we're all turning out these students to the next class, they all need to know somewhat of the same things. The guy teaching the Applied will know what–previous knowledge and all that. It's a group choice. I think probably the teachers teaching Pre-algebra talked about it and this is what they decided. (Interview 2)

Although Fiona made a deliberate choice not to use calculators with the fractions unit, the choice was forced upon her by departmental policies. Given free choice in this issue, Fiona would have used the calculator because it provided another option for the students to learn the concept, and, possibly, another approach for teaching the concept.

> If I had my choice, I would teach these kids how to do fractions on the calculator…They've been taught to add fractions since the 6th grade. So, this is the 4th or 5th time they've seen this, and they still don't know how to do it…If I can use other things, if I can use the calculator, I might figure out another way to tell them what to do. It just gives them another option. It hasn't worked so far; let's try something new. (Interview 2)

Even though the departmental policy conflicted with Fiona's beliefs about helping students be successful, she complied with those policies, carrying with her a stronger conviction about her actions as an independent teacher with her own classroom and the freedom that situation would bring.

Observations of Hope's classes painted a more varied picture about computation. The expected arithmetic operations computing was evident:

> I highly suggested that if they [students] were having problems reducing fractions, they put the fraction in the calculator, and let the calculator reduce it for them because I know a lot of them can reduce fractions, but on tests, they make careless mistakes. I told them to minimize the careless mistakes, check your answer in the calculator. Make sure you did it right. And I did that for both groups. [Applied Algebra and Algebra I] (Interview 3)

In addition, during an observation when students worked on finding the slope of lines, Hope said to her students, "If you have trouble with your signs, use your calculator to check What is a negative divided by a negative? If you're not sure, put it in the calculator." Because of the "classroom environment" belief and the "many tools for success" belief, Hope constantly encouraged the use of the calculator for arithmetic operations computing, although this was not a focus in her lesson planning for instruction.

One lesson for the Applied Algebra class required students to report the mean, median, mode, and standard deviation for given sets of data taken in a certain context. Most of these calculations were fairly simple, except the standard deviation. To relieve the tedium of working with long sets of data and the messy algorithm involved in the standard deviation, Hope chose to use statistical computing that was built into the graphing calculator.

> And standard deviation I don't think I would want to do without the calculator. I personally wouldn't want to do it because the formula is awful. You'd spend more time trying to figure out why you're adding, subtracting, and squaring that you'd lose sight of what the standard deviation is. (Interview 3)

I concluded that Hope used the statistical computing to promote critical thinking in her students and to help them see the relationships among the statistical measures upon which the lesson focused. I also recognized this example as disconfirming evidence for Hope's "compute problems by hand" belief because these problems involved computations that would bury the intent of the mathematics lesson.

At another time in Hope's Applied Algebra class, the students focused on topics in probability, specifically counting principles. She started with an easy example of permutations[12] and showed the class the basic idea of what the permutation principle of counting does.

> To talk about permutations, you usually hear "n things taken r at a time." Another way for you to think about this principle is to say "the number of positions and all the different ways to fill those positions." There is a key on the calculator to help us with this counting. (Observation 5)

Then Hope demonstrated the calculator function to do this "counting" for the students with a much more complex problem, (i.e., the numbers were much larger). Hope chose to use the probabilistic computing function of the graphing calculator to reduce the tedium of the computations. The students worked on mathematics that was not beyond their capability, but the graphing calculator kept the numbers manageable. Because Hope did not require her students to do any computations of permutation problems by hand, I again recognized this instance as more disconfirming evidence of the "compute problems by hand" belief.

During the first observation of Hope's class, part of the lesson focused on work with formulas. The assignment required students to evaluate the formulas at a given value of x. The formulas were both linear and quadratic in form. Hope told her students, "Continue with the formula. In place of a, use x because we will

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[12] A permutation is any arrangement of distinct objects in a particular order.

graph these later. Why must we change the variable from *a* to *x*?" Hope chose to use evaluative computing to help her students with this exercise because she told me in a later interview "they were just not good at substituting."

Hope related a lesson that involved trigonometric computing. Her class discussed finding relationships that could not be measured physically. This discussion expanded into the kinds of physical objects that cannot be measured easily and how mathematics can help in this type of situation. The high school had an ROTC program available; part of the training for that program included safely climbing a tower. Hope used this tower to illustrate the benefits of trigonometry for practical applications.

> We found the measure of the height of the ROTC tower by using the tangent function. You don't need a graphing calculator for that, but we couldn't have done that activity without a calculator. (Interview 3)

I concluded that this activity that used trigonometric computing was a deliberate effort on Hope's part to connect mathematics to real-world applications; it showed her students that mathematics was beneficial in their everyday experiences. This lesson was an outgrowth of the "connected to everyday experiences" belief about mathematics, the "application-based" belief about teaching, the "use real-world applications" belief about learning mathematics, and the "proper tools for many levels of mathematics" belief about students.

At different times in the interviews, Hope stated that she thought about using the calculator for problems that involved computation but "backed off." In one case involving regression, which she taught her students very successfully, they were so overwhelmed by the lesson content that Hope abandoned the idea of using the calculator.

> I said, "Do you want to know how you can get the calculator to help you?" And they said no. They were like—no, that would just confuse me more—so, that was that. (Interview 2)

When I asked Hope if she thought having more buttons to push caused confusion, she said:

> When I taught the quadratic—the quadratic is $y = x^2$. That's easy to put in the calculator; they know how to do that. With the quadratic, they knew where the buttons were because they're on the outside, not in one of the menus. If some function is in a menu, I end up having to repeat it every time they use it. (Interview 3)

I deduced that computation functions of the graphing calculator were helpful as long as they were easily accessible to the students. Those functions that were buried deeply in the several menus of the calculator were cumbersome for the students. If too much button pushing caused confusion for students, then Hope might well avoid using the graphing calculator with no consideration of its use even during lesson planning.

Algebra

Both preservice teachers taught courses based in algebra: Pre-algebra, Applied Algebra, and Algebra I. And, these courses were the classes I observed during student teaching. Therefore, this section examines which content in these algebra courses was suitable to plan use of the graphing calculator and which content was not, based on the classes I observed or classes the preservice teachers discussed with me.

I observed Fiona's class when it worked on simple one-step solutions to inequalities such as $x + 7 > 15$. In the plan for this class, Fiona had her students solve the inequality by hand and use the calculator TEST function to verify that solution. For the sample problem $x + 7 > 15$, students subtracted 7 from both sides to obtain $x > 8$. Then students typed in $x + 7 > 15$ for the calculator and inputted what they believed to be the answer. In addition, the calculator reported 1 or 0 for *true* or *false*, respectively, from the TEST function. This planned approach was a deliberate use of the graphing calculator. However, this lesson also afforded more use of the calculator. The graphing capability allowed Fiona to graph both sides of the inequality and showed a visual of the inequality. After realizing the inequality should be viewed above the line $y = 15$, students would have seen that values greater than 8 satisfy the inequality. I concluded that Fiona did not consider this use of the graphing calculator because of her belief that lower-level students only used the calculator to verify answers. At this point in student teaching, she had no inclination that these students could generate alternate solutions or explore concepts with the calculator.

During another observation of Fiona's class when more complex inequalities were studied, I heard a student questioning Fiona about a particular exercise whose solution was $x < -36$. The student understood that she needed a number smaller than –36, but she was confused about whether she should choose –35 or –37. Fiona's solution was to draw a number line and have the student decide which value to use in the inequality. I saw this event as an opportunity to use the graphing calculator TEST function in conjunction with the number line. I thought the combination of the two strategies might give the student a stronger understanding of the negative integers and the concept of *less than*. I concluded that Fiona had conceptualized the use of the calculator to verify the answer and had not thought about other applications for which the TEST function might be used. I recognized that this event was an impromptu situation and would not fall into a plan for a lesson, but the event illustrated the need for teachers' awareness of calculator uses to facilitate fully using the graphing calculator in mathematics instruction.

Other mathematics for which Fiona used the graphing calculator were one-and-two step equations and creating T-tables for linear functions. In the one-and-two step equations, her plan included graphing each side of the equation as a linear function and looking at the intersection of the two lines as the solution of the equation.

> I want to do this with graphing. After you put the *x* side in Y1 and the other side in Y2, press the GRAPH key. Where the two graphs intersect should be the algebraic solution. (Observation 3)

I concluded that Fiona wanted her students to see the relationship between the two parts of the equation and how the graphical and algebraic solutions matched. The lesson on T-tables for linear functions focused on finding one ordered pair by hand and one ordered pair from the calculator. The second ordered pair from the calculator was obtained by graphing the linear function and using the TRACE function of the calculator. In this fashion, Fiona used the calculator to generate alternate solutions. In each of these plans, Fiona had a particular strategy in mind that the graphing calculator facilitated; thus, her plans developed around the deliberate use of the graphing calculator. In fact, in all my observations of Fiona's classes, she developed lesson plans around the deliberate use of the graphing calculator. However, it was only toward the last part of student teaching that I saw her plans evolve into activities that pursued higher levels of graphing calculator use. (Verifying answers is considered the lowest level of use.)

Observing Hope's classes yielded some of the same concepts in algebra that I observed in Fiona's classes. Both preservice teachers treated one-and-two step equations in the same way, (i.e., graph each side of the equation and look at the intersection of the two lines for the solution to the equation). In Hope's class, a different twist or an added element to this concept was the set of equations that contained a distributive expression that had to be simplified to get the two-step equation. This set of equations was discussed earlier in the chapter. Again, I recognized that Hope planned these lessons around the deliberate use of the graphing calculator to help her students see the relationship between the two lines and the algebraic and graphical solution methods for these equations.

Another unit Hope taught her Applied Algebra groups was the structure of lines and how they work in mathematics. As I discussed earlier, Hope planned several activities for the concept of the slope of a line using the graphing calculator: positive-and-negative slope investigations, large-and-small value slope investigations, and horizontal-and-vertical slope investigations. For each of these, her plans developed around the deliberate use of the graphing calculator because of its visual capabilities.

Near the end of the unit on lines, I observed Hope teaching an application of lines; the application centered on a business that plotted services, durables, and non-durables represented by line equations. It was interesting that Hope abandoned the graphing calculator at this point and resorted to a sketch on the board. She referred to the lines as D (durables), ND (non-durables), and S (services).

Hope What do you notice about the way lines D and ND look?

Student 1 They have the same steepness.

Hope What did we call the steepness?

Student 2 The slope.

Hope What can we say about line S?

Student 1 It goes up faster.

Hope What feature of lines ND and S are the same?

Student 3 They have the same intercept. (Observation 2)

I knew that Hope could devise equations to fit the business application with which she worked that day, and the students could graph them in their calculators using Y1, Y2, and Y3. Instead, she chose to use a hand-sketched graph on the board. I deduced that her choice not to use the graphing calculator at this juncture was an outgrowth of her recognition of a disadvantage in the physical design of the calculator. Hope observed earlier that it is difficult to tell lines apart once they are graphed on the screen. I concluded that she avoided student confusion about which line was which by resorting to the hand sketch where she was able to label the lines D, ND, and S.

Previously I described the lesson on factoring trinomials in which Hope's Algebra I students engaged. The purpose of the lesson was to learn how to factor trinomials. Within that lesson, Hope planned the deliberate use of the graphing calculator to help her students see the relationship between the factors of the trinomial and the locations at which the graph crossed the x-axis. She also used the calculator to help them check their work. Again, she worked with the visual characteristic of the graphing calculator to strengthen the understanding of her students.

Hope told me about her experiences teaching the concept of absolute value. She decided that she would use the computers in the school computer lab "for no other reason but that [she] thought [she] should use the lab and that it was different." Hope observed that her students had real difficulty with the concept. She said that she wrote the lab exercises using the vertical bar symbols that are traditionally used for absolute value, but her students "didn't know what that meant." Hope admitted that the next time she taught this concept she would use the graphing calculator. She thought that her students could get a better grasp of what the graph is and what it says about absolute value. Because I did not see what exercises Hope designed for the lab nor did I actually understand the purpose of the lesson, I came to no conclusions about this deliberate choice not to use the graphing calculators other than she wanted to do "something different."

In Hope's decisions to use the graphing calculator, I found more variation in her choices about deliberate use and non-use. Her lesson planning reflected a strong dependence on the graphing calculator, and she took advantage of the benefits the calculator provided for learning and teaching. Hope had definite ideas about the advantages and disadvantages the calculator provided, and her lesson plans reflected those ideas.

Teachers' Belief Systems and Graphing Calculator Use

Although my research questions did not explicitly address teachers' beliefs, their beliefs about mathematics and mathematics education played a significant role in the decisions the preservice teachers made about the use of the graphing calculator in mathematics instruction. This role was evident in the persistence with which Fiona promoted the critical thinking skills of her students through the use of the graphing calculator, and this role was evident in the types and scope of mathematics that Hope taught by using the graphing calculator with her students.

As I saw it, Fiona's central belief (Green, 1971; Rokeach, 1960) was that all people can be successful in life. Her job as a teacher was to foster that success by providing as many tools as possible to promote the success of her students. Mathematics and the learning of mathematics was a vehicle for developing those skills that produce successful people because she thought:

> It provides a logical way of thinking that includes assessing situations, making and validating conjectures, and reflecting on the reasonableness of a conclusion. (Interview 1)

It was the "success in life" belief, I concluded, that directed the decisions Fiona made about graphing calculator use. Those situations that she found problematic regarding the use of graphing calculators can be traced back to this belief because having the appropriate model of calculator, having worthwhile investigations for teaching topics, having students with an open attitude to new approaches to content, and having the appropriate balance of calculator use and paper-and-pencil manipulations would enhance her teaching of mathematics and her ultimate goal of preparing successful people for society. Likewise, the "success in life" belief affected *how* and *when* Fiona used the graphing calculator in mathematics instruction. Within the limits of the content she was teaching, she used the calculator in several ways to prepare successful people for society. Her learner-focused approach (Kuhs & Ball, as cited in Thompson, 1992) to teaching mathematics was consistent with the "success in life" belief and further strengthened this belief psychologically (Green, 1971; Rokeach, 1960), as decisions to use the graphing calculator were considered and then implemented in her mathematics teaching. After she completed student teaching, I was pleased that Fiona recognized that her lower-level Pre-algebra students were able to do much more with the calculator than "check work," and that she vowed to work harder to use the graphing calculator for higher levels of teaching and learning experiences in mathematics for this type of student.

I concluded that Hope's central belief (Green, 1971; Rokeach, 1960) was that all students could do many levels of mathematics with proper tools. The proper tools included problem solving strategies, group interaction techniques, and graphing calculator technology. For Hope the problematic issues limited, to some degree, the mathematics she could teach because of the time required to create thought-provoking investigations that focused on the concepts, the balance between calculator use and paper-and-pencil manipulations, and student attitudes toward learning. The *how* and *when* of calculator use was very broad and extensive because the calculator opened so many mathematical doors for her students. I understood this belief of "many levels of mathematics for all students" as strengthened by Hope's content-focused approach to the teaching of mathematics (Kuhs & Ball, as cited in Thompson, 1992).

Framework Revisited

In chapter two I presented a framework for this study that included three basic areas I thought would influence graphing calculator use: teachers' beliefs, teachers' personal knowledge of graphing calculators, and local constraints on calculator use. I found that all three of these areas did indeed influence graphing calculator use. However, some were more salient than others. This study refined my thinking about these areas—what was important, what should be added, and what literature was most beneficial in describing and interpreting the data.

I was able to identify ways in which the preservice teachers used graphing calculators in instruction using Simmt's (1997) categories as a starting point. Then, I was able to identify beliefs that the preservice teachers held and connect those beliefs to uses of the calculators. Kuhs and Ball (as cited in Thompson, 1992) informed my thinking concerning the preservice teachers' approaches to teaching mathematics. This information helped me understand the central belief of each preservice teacher. The belief of greatest importance was how they saw the abilities of their students in relation to the mathematics those students could do. The preservice teachers' beliefs about mathematics were also important because these beliefs set the stage for the types of graphing calculator use the teachers chose for the classroom. Both preservice teachers believed that the graphing calculator was a tool for effective instruction and used it accordingly.

In the arena of local constraints, the effect of student resistance was of greatest importance. Other factors attracted the concern and the consideration of the preservice teachers, but the teachers were able to overcome these influences because of their beliefs about teaching and their role in the education of their students.

I initially conceived of the category *teachers' personal knowledge of graphing calculators* as dealing strictly with their knowledge of the machine and how it works. I did not find this to be particularly problematic for the teachers in this study. However, I determined that it was not sufficient to examine the preservice teachers' familiarity with graphing calculators. I found that it was also important to understand the teachers' familiarity with *teaching with graphing calculators*. This encompasses things such as balancing technology and paper-and-pencil work, selecting appropriate tasks, and managing classroom discourse when each student is working independently with a calculator. Figure 5 captures my new understandings.

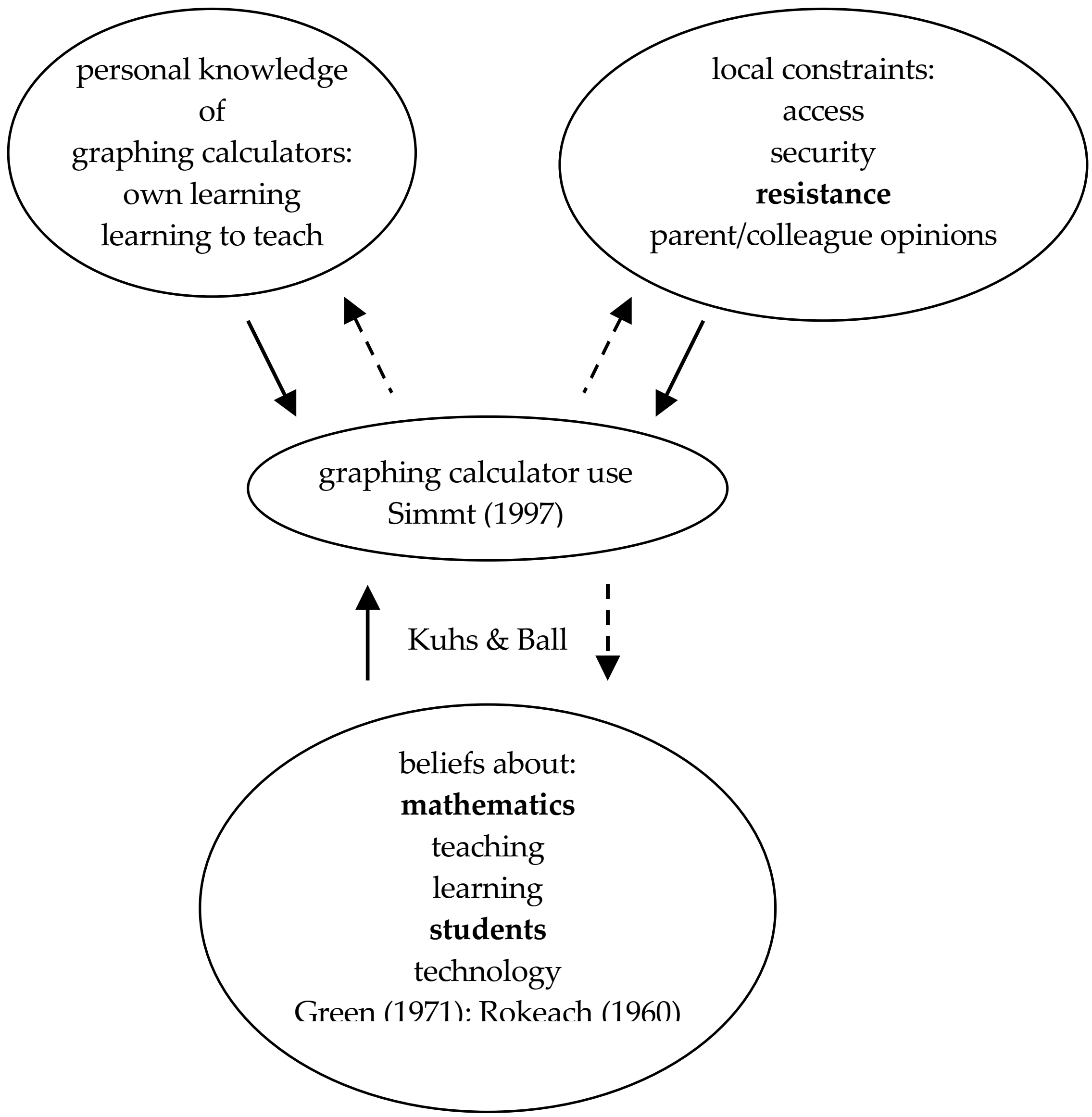

Figure 6: Theoretical framework

CHAPTER 5

SUMMARY AND CONCLUSIONS

The purpose of the study was to investigate preservice teachers' beliefs and practice regarding the use of graphing calculators. Specifically, I was interested in *how* and *when* preservice teachers used the graphing calculator in mathematics instruction and what they found problematic about this use. Data were collected in the form of surveys, essays, classroom observations, individual interviews, and e-mail communications. Data were analyzed in the methods of grounded theory (Creswell, 1998; Merriam, 1998) and interpretations were developed in agreement with that method.

Two preservice secondary mathematics teachers completed student teaching over a ten-week period and the Professional Seminar in Mathematics Teaching over a five-week period during the spring semester of 2001. They were involved in all duties and responsibilities expected of the classroom teacher in a Georgia high school. These activities included record keeping of attendance and other such items required by state, district, and school authorities; attendance at regularly scheduled meetings and those meetings pertinent to the teacher's classes; planning and teaching lessons for Pre-algebra, Geometry, Applied Algebra, and Algebra I courses; and attendance and completion of requirements for the seminar.

Consistent with the findings of Fuller and Bown (1975) and Schwab (1973), the preservice teachers were concerned about classroom environment, teacher actions, and student learning. They exhibited concern in these areas throughout the duration of student teaching. Concern for the content they were teaching was not evident except in planning approaches and strategies that promoted student learning.

The preservice teachers' uses of the graphing calculator were analyzed using Simmt's study (1997) that reported uses of six inservice teachers. The data suggest that the preservice teachers' uses aligned with the uses Simmt described, and the data identified two new uses not reported by Simmt. The preservice teachers' uses of the graphing calculator were as a tool for checking work, for finding graphical solutions, for exploring deeper, richer mathematics, for generating alternate solutions, for simulating real-world phenomena, for visualization, and for motivation. The two novel uses of the graphing calculator were as a tool for simulating real-world phenomena and for motivation.

The preservice teachers found certain situations problematic when using graphing calculators in mathematics instruction. Those situations included time and materials for planning, appropriate amount of use, and student resistance. The preservice teachers' concerns about appropriate amount of use were consistent with the findings of Simonsen and Dick (1997) and Zand and Crowe (1997). The element of student resistance (Heid, 1997; Griffith, 1998) was also a serious problem.

The mathematics with which the graphing calculators were used came under two areas of content: computation and algebra. For both areas, the data suggest that the preservice teachers refrained from using the graphing calculators at times when the teachers thought the calculator might confuse students more because of the mechanics of using the calculators.

Both preservice teachers came to student teaching with sets of beliefs about mathematics and mathematics education that developed out of earlier school experiences and later studies in mathematics education. These beliefs influenced *how* and *when* the graphing calculator was used in mathematics instruction.

Experiences gained during student teaching also influenced these beliefs as the teachers worked through the ten-week period of student teaching.

Conclusions

At first glance, the two preservice teachers represented separate functions, seemingly similar on the surface because of the preservice teachers' responses about mathematics teachers. On second glance, the functions move apart because of the preservice teachers' approaches to teaching mathematics. This divergence manifested itself in the levels of and the extent of use of the graphing calculator. Both preservice teachers taught classes of students that could only be considered lower-level students, and each preservice teacher's beliefs about and expectations of those students' abilities regarding the mathematics those students could do formed the basis for the sharpest divergent pattern. And, yet, the patterns converge and are the same in many significant ways.

The belief that students with low arithmetic skills limit graphing calculator use to verifying answers had one preservice teacher planning lessons around this use. Although the levels of use expanded to include generating alternate solutions, the development of this use was late in the process of student teaching for this preservice teacher. These factors constrained the preservice teacher's classroom and planning actions because of the influence of what she thought was possible in her classroom.

The belief that all students can do many levels of mathematics given appropriate tools, whether technological tools or tools of strategy, opened a broader range of use of the graphing calculator for the second preservice teacher. This broader range was evident in the levels of calculator use and the types of mathematics addressed. For this preservice teacher's students, it appears that the teaching of much deeper and richer mathematics was possible.

Both preservice teachers expressed similar beliefs about mathematics, about students, and about learning. The preservice teachers shared a belief that mathematics should make sense, and they saw mathematics as more than a set of rules and procedures to learn. They also shared the beliefs that students should be critical thinkers and that students learn mathematics through their own mathematical inquiry, which manifested themselves in the preservice teachers enacting the role of facilitator rather than the role of a transmitter of knowledge. The preservice teachers saw mathematical learning as inquiry and saw the graphing calculator as a valuable source of authority in this inquiry.

To promote the graphing calculator as a tool of inquiry, the preservice teachers needed more support for teaching with the calculator technology. They needed resources that provided lesson ideas for the concepts they taught. They also needed guidelines for addressing the concepts with the graphing calculator because teaching with the tool is quite different from learning with the tool.

The model I developed for graphing calculator use and influencing factors is workable. Teachers' beliefs about mathematics and about students strongly influenced the use of graphing calculators in mathematics instruction. The influencing factors of personal knowledge of graphing calculators needs to be broader. It should include learning to teach with the graphing calculator.

Preservice secondary mathematics teachers can and do use graphing calculators in fairly extensive and fairly appropriate ways during student teaching. The categories of use exhibited are as a tool for checking work, for finding graphical solutions, for exploring deeper, richer mathematics, for generating alternate solutions, for simulating real-world phenomena, for visualization, and for motivation.

Implications

In the first chapter, I framed this study as my efforts to understand *how* and *when* preservice teachers use the graphing calculator during student teaching and what those teachers find problematic about that use. After reflection on what I have learned from this study, I drew several implications about various aspects of mathematics education.

Research

This study, partially, is about the beliefs of two preservice teachers regarding mathematics and mathematics education. In my work to understand the influence of these beliefs, it became clear to me that studies of this type require the researcher to practice great care in drawing conclusions. Looking only at surface level statements about teaching mathematics would have led me to conclude that both preservice teachers were the same, when, in fact, they were not. Therefore, studies of this type require the researcher to dig below the surface to get at the meaning behind the surface level words that a participant might use to answer the researcher's inquiries. This "digging below the surface" can be accomplished through follow-up questions in interviews or e-mail prompts.

The conclusions that one reaches from such digging may lead to ways of describing participants. In particular, I labeled one preservice teacher as learner-focused and the other as content-focused. The connotation is that the content-focused teacher placed all her emphasis on the content that she was teaching. However, sufficient evidence exists to show that the preservice teacher that I labeled content-focused was concerned about her students and wanted success for them. Thus, while categorical descriptions may be a useful analytical tool, researchers have an obligation to provide more illuminating details about their participants so as not to paint an incomplete or misleading picture of them.

The preliminary data for this study were collected from surveys that were taken from previous studies or projects. I used these surveys because their worth was previously validated in the work of others. Many times one reads about conclusions drawn about beliefs on the strength of surveys alone. The data suggests that drawing conclusions about beliefs or philosophies from surveys without observing teaching practices may lead to false conclusions because putting the survey situation into a given context often changes the answers given in a vacuum.

Teacher Education

Teacher education programs constantly need revision to properly prepare the teaching force for tomorrow's classrooms. This study suggests that preservice secondary mathematics teachers need extensive experiences with graphing calculator use and applications in teaching mathematics. Although preservice teachers may have extensive experiences using graphing calculators in their own learning of mathematics, this does not transfer automatically into being able to successfully integrate calculators into instruction. Therefore, preservice and inservice teachers need planned support through rich and numerous experiences with graphing calculator technology in order to more fully use graphing calculators in mathematics instruction. In particular, they need opportunities to examine the high school curriculum and determine when and where calculators could be beneficial in instruction and to anticipate problems that might arise when using the technology in a particular context. They need experiences developing lesson plans that address these concerns (i.e., appropriate curriculum and context).

Further education of preservice and inservice elementary mathematics teachers about the appropriate and beneficial use of calculators in the elementary classroom needs exploration and implementation. Research studies show that children are not harmed by the appropriate use of calculators in the elementary and secondary mathematics classroom. The data from this study showed that elementary teachers play a large role in the attitudes and biases that students bring to the use of graphing calculators in the secondary mathematics classroom.

This study indicates that the secondary mathematics teacher education program should help preservice teachers identify their beliefs about mathematics, about mathematics teaching and learning, and about students and what those beliefs imply about the personal philosophies regarding teaching mathematics and graphing calculator use. If teachers are aware of their beliefs and biases, they can relate what they are reading and hearing in their classes and what they are seeing in schools to their beliefs and, possibly, revise those beliefs. Then, the preservice teachers can make deliberate instructional decisions based on an awareness of these beliefs. Including in teacher education research that has shown the benefits of graphing calculator use might help preservice teachers bridge the gap between personal beliefs and actual practice.

The model of influences on graphing calculator use suggests that particular pressure points exist for teacher education. Because beliefs about student abilities and the mathematics they can do proved to be such a strong influence on graphing calculator use, teacher education programs need to provide experiences for preservice teachers about which students can do what mathematics to uncover possible biases in this area. Additionally, preservice teachers need specific suggestions for pedagogy that might overcome student resistance to graphing calculator use.

To foster the use of graphing calculators in student teaching and beyond, teacher education programs have a responsibility to support their preservice teachers in a variety of ways. As I mentioned earlier, experiences with lesson planning for graphing calculator use based on study of appropriate curriculum is one way. A second way is experiences with pedagogy to overcome or, at least, better cope with student resistance. And, a third way is researching school placements for student teaching that encourage and provide opportunities to use graphing calculators in mathematics instruction during student teaching.

Curriculum Development

The positive impact of graphing calculator use has been documented in research. Mathematics educators need good resources for calculator activities that enhance instruction. These resources should range over the entire scope of secondary mathematics, in particular, from pre-algebra concepts to calculus concepts. Many textbooks now include graphing calculator investigations for content in their texts. This additional material included in the text is a step in the right direction; however, not every school district adopts textbooks of this nature. Therefore, supplemental materials should be developed that suggest and outline graphing calculator investigations for the concepts taught in school mathematics. This study suggests that if teachers are continually forced to spend huge amounts of time looking for or designing activities and investigations that support the content they are teaching, those teachers are less likely to trouble themselves in the effort to use graphing calculator technology in mathematics instruction.

Recommendations for Future Research

The participants in this study were atypical in several ways. They were decidedly older and more mature than most preservice teachers whose average age is 21 or 22. The mathematics backgrounds of these two teachers were stronger than is normally seen in preservice secondary mathematics teachers. Moreover, the life experiences were much different from typical preservice teachers. A replication of this study with typical preservice secondary mathematics teachers would be useful in order to determine if the factors that influence graphing calculator use differ.

A similar study with preservice secondary mathematics teachers of other backgrounds (e.g., preservice teachers with a business background) could be instructive to teacher educators. The practice of changing from other careers to the career of teaching is becoming a popular career path for many people of various backgrounds. Comparing the beliefs that are prominent in that study might lead to other discoveries about graphing calculator use and the mathematics associated with that use.

A similar study that contrasts preservice teachers' use of graphing calculators with upper level students and lower level students might reveal further beliefs that affect graphing calculator use. Studies of this type have been done with inservice teachers with many years of experience, but few, if any, have been conducted involving preservice teachers.

Concluding Remarks

This study suggests that preservice secondary mathematics teachers can use graphing calculators productively in instruction. However, these teachers faced a number of internal and external obstacles to using graphing calculators to their fullest advantage. We cannot afford to waste technological advances that will enhance mathematics instruction because we fail to remove the obstacles that make teaching with that technology problematic for teachers. Bert Waits' comment from Herrera's interview succinctly captures my thoughts:

> The people who oppose the integration of handheld technology in the teaching and learning of mathematics are no doubt well intentioned, but they are simply harming our children. These people deny our children the best education because they are not allowing children to benefit from the advances in teaching that technology has created. (Herrera, 2001, p. 28)

REFERENCES

Austin, J. S. (1997). Effect of graphing calculator use on student achievement in college algebra: Gender and age related differences. (University of Missouri-Kansas City, 1996). Dissertations Abstracts International, 57, 3433A.

Bialo, E., & Erickson, L. (1985). Microcomputer courseware: Characteristics and design trends. *Journal of Computers in Mathematics and Science,4*, 27 – 32.

Bitter, G. G., & Hatfield, M. M. (1993). Integration of the Math Explorer calculator into mathematics curriculum: The Calculator Project report. *Journal of Computers in Mathematics and Science Teaching, 12*, 59 – 81.

Bright, G. W., & Williams, S. E., (1994). Research and evaluation: Creating a complete picture of the impact of calculator use on mathematics teaching and learning. In L. Lum (Ed.) *Proceedings of the Sixth International Conference on Technology in Collegiate Mathematics* (pp. 88 – 98). Reading, MA: Addison-Wesley.

Brown, C. A., & Borko, H. (1992). Becoming a mathematics teacher. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 209 – 239). New York: Macmillan.

Brown, S. I., Cooney, T.J., & Jones, D. (1990). Mathematics teacher education. In W. R. Houston (Eds.), *Handbook of research on teacher education* (pp. 639 – 656). New York: Macmillan.

Christmann, E. P., & Badgett, J. L. (1997). The effects of computers and calculators on male and female statistics achievement. *Journal of Computing in Higher Education, 9,* 49 –58.

Cooney, T. J. (1999). Conceptualizing teachers' ways of knowing. *Educational Studies, 38,* 163 –187.

Cooney, T., Shealy, B., & Arvold, B. (1998). Conceptualizing belief structures of preservice secondary mathematics teachers. *Journal for Research in Mathematics Education*, 29, 306-333.

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage Publications.

Demana, F., Schoen, H. L., & Waits, B. (1993). Graphing in the K-12 curriculum: The impact of the graphing calculator. In T. Romberg, E. Fennema, & T. Carpenter (Eds.), *Integrating research on the graphical representation of functions* (pp. 216 – 224). Hillsdale, NJ: Lawrence Erlbaum.

Demana, F., & Waits, B. K. (1992). A computer for all students. *The Mathematics Teacher*, *84*(2), 94 –95.

Dick, T. (1992). Supercalculators: Implications for calculus curriculum, instruction, and assessment. In J. T. Fey (Ed.), *Calculators in Mathematics Education: 1992 Yearbook of the National Council of Teachers of Mathematics* (pp. 145 – 157). Reston, VA: NCTM.

Dick, T., & Shaughnessy, M. (1988). The influence of symbolic/graphic calculators on the perceptions of students and teachers toward mathematics. In M. Behr, C. Lacampagne, & M. Wheeler (Eds.), *Proceedings of the Tenth Annual Meeting of PME-NA* (pp. 145 – 157). Reston, VA: NCTM.

Drier, H. S. (1998). How are graphing calculators used in mathematics classrooms? Teachers' beliefs and practices. *Curry Journal of Education*, *1*(1), 39 – 50.

Dunham, P. H. (1995). Calculator use and gender issues. *Association for Women in Mathematics Newsletter, 25*(2), 16 – 18.

Dunham, P. H. (2000). Hand-held calculators in mathematics education: A research perspective. In E. D. Laughbaum (Ed.), *Hand-held technology in mathematics and science education: A collection of papers* (pp. 39 – 47). Columbus, OH: Teachers Teaching with Technology (T^3).

Dunham, P. H., & Dick, T. P. (1994). Research on graphing calculators. *Mathematics Teacher, 87*, 440 –445.

Dunham, P. H., & Osborne, A. (1991). Learning how to see: Students' graphing difficulties. *Focus on Learning Problems in Mathematics, 13*(4) 35 – 49.

Ebert, C. L. (1994). Multiple layers of technology—an assessment of videotapes of prospective secondary teachers utilizing graphing calculators to teach quadratic functions. In L. Lum (Ed.), *Proceedings of the Sixth Annual International Conference on Technology in Collegiate Mathematics* (pp. 483 – 489). Reading, MA: Addison-Wesley.

Farrell, A. M. (1996). Roles and behaviors in technology-integrated precalculus classrooms. *Journal of Mathematical Behavior, 15*, 35 – 53.

Fine, M. (1994). Working the hyphens: Reinventing self and other in qualitative research. *Handbook of Qualitative Research*, 70 – 82.

Fine, A. E., & Fleener, M. J. (1994). Calculators as instructional tools: Perceptions of three preservice teachers. *Journal of Computers in Mathematics and Science Teaching, 13,* 83 – 100.

Fleener, J. (1994). *A research study of teachers' beliefs about calculator use.* Paper presented at the Annual Meeting of the Association for the Advancement of Computing in Education San Diego, CA. (ERIC Document Reproduction Service No. ED 372914)

Fleener, M. J. (1995). The relationship between experience and philosophical orientation: A comparison of preservice and practicing teachers' beliefs about calculators. *Journal of Computers in Mathematics and Science Teaching, 14*, 359 – 376.

Fuller, F. F., & Bown, O. H. (1975). Becoming a teacher. In K. Ryan (Ed.) *The Seventy-fourth Yearbook of the National Society for the Study of Education* (pp. 25 – 52).Chicago: University of Chicago Press.

Foster, A., Rath, J., & Winters, L. (1986). *Algebra two with trigonometry*. Columbus, Ohio: Merrill.

Futch, L. D., & Stephens, J. C. (1997). The beliefs of Georgia teachers and principals regarding the NCTM Standards: A representative view using the Standards" Belief Instrument (SBI). *School Science and Mathematics, 97,* 242 – 247.

Galindo-Morales, E. (1995). Visualization in the calculus class: Relationship between cognitive style, gender, and use of technology. (The Ohio State University, 1994). *Dissertation Abstracts International, 55*, 3125A.

Giamati, C. M. (1991). The effect of graphing calculator use on students' understanding of variations on a family of equations and the transformations of their graphs. (University of Michigan, 1990). *Dissertation Abstracts International, 52,* 103A.

Green, T. F. (1971). *The activities of teaching.* New York: McGraw-Hill.

Griffith, L. K. (1998). Impact of technology on pedagogy. In G. Goodell (Ed.) *Proceedings of the Eleventh Annual International Conference on Technology in Collegiate Mathematics* (pp. 146 - 148). Reading, MA: Addison-Wesley.

Groves, S., & Stacey, K. (1998). Calculators in primary mathematics: Exploring number before teaching algorithms. In L. J. Morrow (Ed.), The teaching and learning of algorithms in school mathematics (pp. 120 – 129). Reston, VA: NCTM.

Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Researcher, 15*(5), 5 – 12.

Haimes, D. H. (1996). The implementation of a "function" approach to Introductory algebra: A case study of teacher cognitions, teacher actions, and the intended curriculum. *Journal for Research in Mathematics Education, 27*, 582 – 602.

Heid, M. K. (1997). The technological revolution and the reform of school mathematics. *American Journal of Education, 106*, 5 – 61.

Heid, M. K., & Baylor, T. (1993). Computing technology. In P. S. Wilson (Ed.) *Research Ideas for the Classroom: High School Mathematics* (pp. 198 – 216). New York: Macmillan.

Hembree, R., & Dessart, D. (1986). Effects of hand-held calculators in precollege Mathematics education: A meta-analysis. *Journal for Research in Mathematics Education, 17*, 83 – 99.

Hembree, R., & Dessart, D. (1992). Research on calculators in mathematics education. *NCTM Yearbook*. Reston, VA: NCTM.

Herrera, T. (2001). Handheld technology: An essential ingredient in teaching and learning mathematics (An interview with Bert Waits). *ENCfocus, 8*, 26 – 29.

Heshusius, L. (1994). Freeing ourselves from objectivity: Managing subjectivity or turning toward a participatory mode of consciousness? *Educational Researcher, 23*(3), 15 – 22.

Hesse-Biber, (1993). *HyperRESEARCH.* Computer software, CA: ResearchWare, Inc.

Hollar, J. C. (1997). The effects of a graphing approach college algebra curriculum on students' understanding of the function concept. (North Carolina State University, 1996). *Dissertation Abstracts International, 57*, 2924A.

Jones, P. L., & Boers, M. A. (1993). Some gender difference in attitudes and mathematics performance with graphics calculators. In L. Lum (Ed.), *Proceedings of the Fifth International Conference on Technology in Collegiate Mathematics* (pp. 173 – 177). Reading, MA: Addison-Wesley.

Jost, K. L. E. (1992). *The implementation of technology in the calculus classroom: An examination of teacher beliefs, practice and curriculum change.* Unpublished doctoral dissertation, Syracuse University, Syracuse, New York.

Keller, B., & Russell, C. (1997). Effects of the TI-92 on calculus students solving symbolic problems. *International Journal of Computer Algebra in Mathematics Education, 4,* 77 – 97.

Kilpatrick, J. (1994). Mathematics instruction: Contemporary research. In T. Husen & T. N. Postlethwaite (Eds.), *The international encyclopedia of education* (2nd ed.) (Vol. 6 pp. 3643 – 3647). Oxford, England: Elsevier Science Ltd.

Kinney, D. P. (1997). The effect of graphing calculator use and the Lesh translation model on student understanding of the relationship between function and derivative in a nonrigorous calculus course. (University of Minnesota, 1997). *Dissertation Abstracts International, 57,* 5090A.

May, C. M. (1994). *Factors affecting the integration of graphing calculator technology in the secondary precalculus classroom: attitudes, teacher, training, and curriculum issues*. Unpublished dissertation, The University of Texas at Austin.

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

Mesa, V. M. (1997). The role of the graphing calculator in solving problems on functions. (Master's thesis, University of Georgia, 1996). *Masters* Abstracts International, 35, 937.

Munby, H. (1982). The place of teachers' beliefs in research on teacher thinking and decision making, and an alternative methodology. *Instructional Science, 11,* 201 – 225.

National Council of Teacher of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: NCTM.

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

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*(3), 307 – 332.

Penglase, M, & Arnold, S. (1996). The graphics calculator in mathematics education: A critical review of recent research. *Mathematics Education Research Journal, 8*, 58 – 90.

Random House dictionary of the English language, (unabridged ed.). (1971). New York: Random House.

Rich, B. (1991). The effect of the use of graphing calculators on the learning of function concepts in precalculus mathematics. (University of Iowa, 1990). *Dissertation Abstracts International, 52,* 835A.

Rokeach, M. (1960). *The open and closed mind.* New York: Basic Books.

Rokeach, M. (1968). *Beliefs, attitudes, and values: A theory of organization and change.* San Francisco: Jossey-Bass.

Runde, D. C. (1997). *The effect of using the TI-92 on basic college algebra students' ability to solve word problems.* Research Report (143), Manatee Community College, Florida. (ERIC Document Reproduction Service No. ED 409046)

Ruthven, K. (1990). The influence of graphic calculator use on translation from graphic to symbolic forms. *Educational Studies in Mathematics, 21*, 431 – 450.

Schifter, D. (1999). Relationships between research and the NCTM standards: An introduction. *Journal for Research in Mathematics Education, 30*, 2.

Schwab, J. J. (1973). The practical 3: Translation into curriculum. *School Review, 81*(4), 501 – 522.

Shealy, B., Arvold, B., Zheng, T., & Cooney, T. (1993). The evolution of preservice secondary mathematics teachers' beliefs. In J. Becker & B. Pence (Eds.), *Proceedings of the Fifteenth Annual Meeting North American Chapter of the International Group for the Psychology of Mathematics Education,* 2, 224 – 230. Pacific Grove, CA.

Shoaf-Grubbs, M. M. (1994). The role of the graphing calculator in helping the weaker mathematics student succeed in the game of "Catch up." In L. Lum (Ed.), *Proceedings of the Sixth International Conference on Technology in Collegiate Mathematics* (pp. 695 – 701). Reading, MA: Addison-Wesley.

Simmt, E. (1997). Graphing calculators in high school mathematics. *Journal of Computers in Mathematics and Science Teaching*, 16, 269 – 289.

Simonsen, L. M., & Dick, T. P. (1997). Teachers' perceptions of the impact of graphing calculators in the mathematics classroom. *Journal of Computers in Mathematics and Science Teaching, 16*, 239 – 268.

Siskind, T. G. (1995). The effect of calculator use on mathematics achievement for rural high school students. *Rural Educator, 16*(2), 1 – 4.

Slavit, D. (April, 1994). *The effect of graphing calculators on students' conceptions of function*. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, April, 1994. (ERIC Document Reproduction Service No. 374 811)

Slavit, D. (1996). Graphing calculators in a "hybrid" Algebra II classroom. *For the Learning of Mathematics, 16*, 9 – 14.

Smith, K. B., & Shotsberger. (1997). Assessing the use of graphing calculators in college algebra: Reflecting on dimensions of teaching and learning. *School Science and Mathematics, 97*, 368 –376.

Strudler, N.B. (1993). Staff development and technology: A position paper. *Journal of Computing in Teacher Education, 9*(4), 8 – 9.

Tharp, M. L., Fizsimmons, J. A., & Brown Ayers, R. L. (1997). Negotiating a technological shift: Teacher perception of the implementation of graphing calculators. *Journal for Computers in Mathematics and Science Teaching, 16*, 551 – 575.

Thompson, A. (1984). The relationships of teachers' conceptions of mathematics teaching to instructional practice. *Educational Studies in Mathematics, 15*, 105 –127.

Thompson, A. (1985). Teachers' conceptions of mathematics and the teaching of problem solving. In E. A. Silver (Ed.), *Teaching and learning mathematical problem solving: Multiple research perspectives* (pp. 281 – 294). Hillsdale, NJ: Lawrence Erlbaum.

Thompson, A. (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.

Upshaw, J. T. (1994). The effect of the calculator-based, graph-exploration method of instruction on advanced placement calculus achievement. (University of South Carolina, 1993). *Dissertation Abstracts International, 54*, 4023A.

Waits, B., & Demana, F. (2000). The role of graphing calculators in mathematics reform. In E. D. Laughbaum (Ed.), *Hand-held technology in mathematics and science education: A collection of papers* (pp. 72 - 75). Columbus, OH: Teachers Teaching with Technology (T^3).

Wilson, M., & Krapfl, C. (1994). The impact of graphics calculators on students' understanding of function. *Journal of Computers in Mathematics and Science Teaching, 13*, 252 – 264.

Wilson, P. S., Anderson, D., Leatham, K., Lovin, L., & Sanchez, W. (1999). Giving voice to mentor teachers. *Proceedings of the Twenty First Annual Meeting North American Chapter of the International Group for the Psychology of Mathematics Education,* (pp. 811 – 817). Cuernavaca, Mexico: Universidad Autonoma del Estado de Morelos.

Zand, H., & Crowe, W. D. (1997). Novices entering Mathematics 2: The graphic calculator and distance learners. *Computers in Education, 29,* 25 – 32.

APPENDIX A

MATHEMATICS AUTOBIOGRAPHY

Please provide me with a brief "mathematics autobiography." Include (but do not limit yourself to) the answers to the following questions:

- Are you "good" at mathematics? Explain.
- Do you like or dislike mathematics? Why?
- Do you like or dislike all mathematics equally? If not, which do you like or dislike the most? Why?
- Who or what influenced (either positively or negatively) your feelings about mathematics?
- How do you feel about teaching mathematics?

APPENDIX B

AIM – AT – II

Strongly Agree = 4 Agree = 3 Disagree = 2 Strongly Disagree = 1

		SA	A	D	SD
1.	Students should be allowed to use calculators on standardized tests.	4	3	2	1
2.	Calculator use will cause a decline in basic arithmetic facts.	4	3	2	1
3.	Calculators make mathematics fun.	4	3	2	1
4.	When solving problems with calculators, students don't need to show their work on paper.	4	3	2	1
5.	More difficult mathematics problems can be done when students have access to calculators.	4	3	2	1
6.	Students understand math better if they solve problems using paper and pencil.	4	3	2	1
7.	Students should not be allowed to use calculators until they have mastered the concept.	4	3	2	1
8.	If students don't know their basic arithmetic facts by 5th grade, they should be allowed to use a calculator.	4	3	2	1
9.	Using calculators will free students to explore alternative solution strategies.	4	3	2	1
10.	Calculators should be used only to check work once the problem has been worked out on paper.	4	3	2	1

11.	Calculators should not be used on math homework.	4	3	2	1
12.	Using calculators will cause students to lose basic computational skills.	4	3	2	1
13.	Math is easier if a calculator is used to solve problems.	4	3	2	1
14.	Calculator skills are as important as paper and pencil computational skills.	4	3	2	1
15.	Continued use of calculators will cause a decrease in student estimation skills.	4	3	2	1
16.	The calculator can be used to explore mathematical concepts.	4	3	2	1
17.	Students should be allowed to use calculators even before they understand the underlying concepts.	4	3	2	1
18.	Calculators are only tools for doing calculations more quickly.	4	3	2	1
19.	Calculators should not be used until students know their arithmetic facts.	4	3	2	1
20.	The teacher should decide when it is appropriate for students to use calculators.	4	3	2	1
21.	Calculator use encourages problem solving.	4	3	2	1
22.	Calculators should only be used by advanced students.	4	3	2	1
23.	Incorporating calculators into teaching requires changing the types of problems assigned.	4	3	2	1
24.	Students can gain understanding of computational procedures by using calculators.	4	3	2	1
25.	Calculators can be used effectively to check answers to homework problems.	4	3	2	1
26.	Students should learn the paper and pencil long division	4	3	2	1

algorithm before using the calculator to divide.

27. The major value of calculators in mathematics classes is to save time performing computations. 4 3 2 1

28. It is not necessary to change what is taught in order to effectively use calculators. 4 3 2 1

29. It is not appropriate for calculators to be used in some mathematics classes. 4 3 2 1

APPENDIX C

RADIATE/PRIME ITEMS

Consider the following similes. Learning mathematics is like:

working on an assembly line	watching a movie	Other________________
cooking with a recipe	Picking fruit from a tree	
working a jigsaw puzzle	conducting an experiment	
building a house	creating a clay sculpture	

a) Choose the simile that you believe best describes learning mathematics and explain your choice.

b) Choose the simile that you believe does not describe learning mathematics very well and explain your choice.

Consider the following similes. A mathematics teacher is like a:

news broadcaster	entertainer	Other_________________
doctor	orchestra conductor	
gardener	Coach	
missionary	social worker	

a) Choose the simile that you believe best describes a mathematics teacher and explain your choice.

b) Choose a simile that you believe does not describe a mathematics teacher very well and explain your choice.

APPENDIX D

CONTRACT FOR RESEARCH STUDY

I, _________________________, understand that as a participant in the doctoral research study conducted by Teresa G. Banker, I must complete the following set of activities prior to student teaching:

- write a mathematics autobiography,
- complete the AIM – AT – II survey,
- complete the RADIATE/PRIME survey items,
- and, participate in an interview, approximately 45 minutes in length, about the above items.

During the ten weeks of student teaching, I must complete the following set of activities:

- each week, via e-mail, provide Mrs. Banker a list of the lessons I will teach the following week,
- reply via e-mail to a bi-weekly question from Mrs. Banker about teaching,
- during weeks 3 through 5, be observed for two class periods by Mrs. Banker and be interviewed once about these two observations,
- and, during weeks 7 through 9, be observed for two class periods by Mrs. Banker and be interviewed once about these two observations.

And, finally, I will be expected to write a parent response letter, either as an exercise in EMAT 4950 / 6950 or as a separate exercise. I will be expected to verify data analyses for interpretive agreement/disagreement with emerging categories, as directed by Mrs. Banker.

Name (I will type in the student's name)________

Signature____Date__________