

THE GOOD, THE BAD, AND THE UGLY:  
THE INTEGRATION OF COMPUTING TECHNOLOGY INTO CALCULUS CLASSES

by

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(Under the Direction of Jeremy Kilpatrick)

ABSTRACT

This study investigated different calculus professors' conceptions about mathematics and mathematical learning, calculus teaching with or without the use of computing technology, and the experiences in which those conceptions were grounded. Through the qualitative research methodology called grounded theory, six college professors were purposefully selected and studied. The results showed the professors' perceptions of the effects of technology use on pedagogy and students' learning; their perceptions of barriers and challenges to the adoption and use of technology for teaching and learning calculus; and their experience, knowledge, and motivation for adopting instructional technology that made unique and significant contributions to explaining faculty use of technology for teaching and learning calculus. Some professors were categorically opposed to the use of computing technology in calculus, but others envisioned that computing technology could play a multitude of roles in their calculus classrooms. The more that the calculus professors wanted to focus on real-world applications and wanted students to apply calculus concepts in their academic disciplines, the more they were concerned about their own ability to facilitate such learning and the need to integrate computing technology into calculus. The more that the calculus professors focused on procedural understanding in mathematics and

on teacher-centered lessons, the more they were concerned about students misusing computing technology and failing to develop a proper understanding of calculus concepts.

INDEX WORDS: Calculus, computing technology, conceptions, undergraduate mathematics education

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with appreciation

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## CHAPTER 1: INTRODUCTION

Technology is changing the way we teach.  
Not because it's *here*, but because it's *everywhere*.  
John Kenelly (quoted in K. B. Smith, 2000, p. 234)

At the beginning of the 21st century, technology is gaining recognition as the driving force of scientific progress as well as a key source of national economic welfare. Simultaneously, higher education is now perceived as the conduit for transition from a declining industrial age to a developing information age. Over the last three decades, the emergence of the Internet, accompanied by rapid advances in computing and communication technology, has dramatically changed the landscape of higher education. The use of computer technology has evolved from data storage to become a common component in teaching and learning, including areas like research and information distribution. In colleges and universities around the world, instructors in all disciplines are using various forms of technology to improve instruction and enrich the classroom experience for their students. In particular, instructors of undergraduate mathematics now have computing technology tools available that allow a more interactive and comprehensive form of teaching than has previously been possible. These tools are widely available, accessible, and cost-effective, and have been proven to enhance the learning process of a mathematics student. Given the overwhelming evidence of the advantages of computing technology, one might assume that this technology has been fully integrated into mathematics classrooms. Despite the vast advances in computing technology, however, along with its increased availability, many mathematics instructors are still not incorporating this technology into curricula or classrooms.

## **Technology in Higher Education**

As higher education becomes more technologically driven, computing technology is being heralded as an agent of change. Many researchers have noted the trend among colleges and universities to transform the nature of the courses and degree programs they offer by creating new instructional delivery methods (Adams, 2002; Bates, 2001; Becker & Devine, 2007; Bullock & Schomberg, 2000; Harley, 2001). The new products and technologies are constantly reshaping methods and materials used for classroom instruction. Course management software packages such as WebCT, combined with broadband Internet access, have made the delivery of curriculum materials over the Internet a common practice (Jones, Asensio, & Goodyear, 2000). As a result, the United States has seen an explosive growth of online universities such as Nova and the University of Phoenix. As technology has become more prevalent in all dimensions of the higher education system, college faculties have witnessed many advances in the functions of educational technologies. These technologies are expanding beyond their existing functions as they evolve into novel applications, including the ability to offer course casting (audio or video online course broadcasting) and online tutoring.

Although the dominant view in higher education about computing technology has been that it will reduce costs and make education more accessible and more effective, the penetration of this technology into undergraduate teaching practices shows a great disparity across colleges (Adams, 2002; Bates, 2001; Bruff, 2009; Bullock & Schomberg, 2000; Crawford, 2003; Davidson-Shivers, 2002; White & Myers, 2001). Technology use and expertise among faculty and students at higher education institutions varies tremendously. Many institutions have added the effective use of technology to their criteria for awarding tenure to faculty members (e.g.,

Seton Hall University), and some institutions now require every student to have a personal computer (e.g., the University of Florida).

Understandably, then, the use of computing technology in higher education has created controversy and excitement. It has, however, also remained highly individualized because of disparate faculty interests, high levels of faculty autonomy, and wide variance in technology expertise evidenced among faculty in colleges and universities (Davidson-Shivers, 2002; Ertmer, Gopalakrishnan, & Ross, 2001; Howland & Wedman, 2004). In a research study of 33,398 faculty members at 378 U.S. institutions of higher education (K. C. Green, 2000), 87% of the faculty was convinced of the benefits of the use of computing technology for education, but only 22% used computing technology for instruction in undergraduate classes. Several researchers have identified having a positive attitude toward and expertise with computing technology as a critical variable in the adoption and subsequent integration of these processes (Becker & Devine, 2007; Harley, 2001; Zhao & Cziko, 2001).

Since the integration process demands fundamental changes in pedagogy, curriculum, and assessment, which significantly affect the role of the instructor, faculty members must be convinced of the feasibility of using a particular computing technology before assimilation can occur (Ertmer, 1999; Lan, 2001; Liaw, 2002; Tucker & Leitzel, 1995). Among the issues preventing the incorporation of computing technology into higher education are barriers such as a lack of institutional and financial support, time, technical knowledge, technology support, and reliable technology (Betts, 2001; Groves & Zemel, 2000; Kersaint, Horton, Stohl, & Garofalo, 2003; Khadivi, 2006; McCracken, 2008; Morris & Finnegan, 2008). Several researchers have also identified the establishment of a department-wide vision or rationale consistent with the values, histories, students, faculties, and missions of the institution as one of the key components

of successful technology integration (Milheim, 2001; Rice & Miller, 2001; Roblyer & Knezek, 2003; D. L. Rogers, 2000).

### **Computing Technology and Undergraduate Mathematics Education**

For more than three decades, the undergraduate mathematics education community has been experimenting with and debating the advantages of computing technology. The advancements in computing technology have changed not only how some mathematics faculty members teach, but also what is taught and when it is taught (Hillel, 2001; Thomas & Holton, 2003). The availability of computing technology has elevated the importance of certain mathematical topics like discrete and nonlinear mathematics while simultaneously decreasing the importance of mathematical skills such as paper-and-pencil arithmetic and symbolic manipulation. Increased access to technology has also provided research tools for exploring the properties of mathematical structures and objects in fractal geometry and chaos theory, and it has created new choices about content and pedagogy by providing new ways to represent mathematical concepts (Alsina, 2001). Examples of these new choices include the visualization of mathematical objects with two- and three-dimensional graphics and the creation of an interactive environment in which students can explore and experiment with vectors, matrices, and transformations (Anthony, Hubbard, & Swedosh, 2000; Hillel, 2001; Thomas & Holton, 2003).

The integration of computing technology into undergraduate mathematics education started as a support in the learning of traditional mathematics curriculum topics, such as solving equations, differentiating, integrating, and showing slope fields in differential equations (Baldwin, 1998; Heid, 2002; Hillel, 1993; Palmiter, 1986). Later, technology integration efforts expanded into designing a technology-enhanced curriculum for various new topics, including

cryptography, chaos theory, group theory, and linear algebra. Recently, a large number of colleges and universities have started to offer online mathematics courses. These courses range from basic developmental mathematics through college algebra, trigonometry, calculus, and abstract algebra.

Nevertheless, in a very real sense, computing technology has failed to penetrate the undergraduate mathematics curriculum. Some of these failures can be found in the breadth of utilization, such as the proportion of departments and courses in which it is used, or the proportion of faculty using it as part of the instructional process. Others reflect a shortfall in the depth to which technology is integrated into individual courses and into the curriculum as a whole (Santucci, 2007). In collegiate mathematics education, the use of computing technology has remained a highly personal decision for faculty members. A huge gap remains between the availability of computing technology in mathematics departments, and its effective use and integration into mathematics instruction by the faculty (Hillel, 2001; Santucci, 2007).

As part of higher education, mathematics faculty members hold various perspectives regarding the role of computing technology in their mathematics instruction and its role in the student's learning process. Although many instructors engage in innovative forms of research and teaching projects, many others do not want to bring computing technology into their classrooms. According to Gadanidis, Kamran, and Liang (2004), the main barrier to the use of computing technology in the mathematics classroom is "the inability of American college mathematicians to recognize the value of such facilities and their unwillingness to make the effort to use the facilities which are available" (p. 279). Despite the availability of various forms of computing technology, their penetration into undergraduate mathematics teaching practice has been very slow and reflects a great disparity across colleges (Hazzan & Zazkis, 2003; Holton,



2001; Santucci, 2007). Research indicates that although technological tools have been acquired and installed on campuses throughout the country, the use and integration of these tools into course instruction by mathematics faculty has lagged behind (Healey, 2000; Santucci, 2007). As Hillel (2001) succinctly stated, undergraduate mathematics education “is still dominated by the ‘chalk-and-talk’ paradigm” (p. 64).

### **Calculus and the Calculus Reform Movement**

Historically, calculus has been, and will likely continue to be, the most important course in the undergraduate mathematics curriculum. For the majority of students, it is the last course in which they will form, adjust, or change their image of mathematics and the process of learning mathematics. Furthermore, calculus has also been, and will probably continue to be, a *gateway class* for future teachers, scientists, economists, engineers, and mathematicians. Thus, the calculus course deserves special attention and requires substantial involvement and effort by all undergraduate mathematics instructors.

In the last three decades, mathematics instructors have been subjected to a constant pressure to change the ways in which calculus is taught and learned. Several national organizations have declared a state of emergency in undergraduate calculus teaching (Committee on the Undergraduate Program in Mathematics, 1991; National Research Council, 1991; National Science Foundation, 1996). These declarations of crisis in calculus teaching have variously been based upon high student failure rates (Hoft, 1991); poor teaching abilities of instructors (Kasten, 1988; Kolata, 1987); inadequate student preparation (Cole, 1993; Holton, 2001); limited use of computing technology (Cole, 1993; Curtis & Northcutt, 1988); and a nearly uniform nationwide calculus curriculum based heavily on memorization and procedural learning (Davis, 1989; Jost, 1992).

To address concerns about calculus instruction, a series of conferences were organized by concerned mathematicians in the 1980s to determine which aspects of instruction needed to be changed and the best ways to implement the changes (Jost, 1992). During those conferences, participants argued that the calculus curriculum should incorporate the use of computing technology, and that calculus ideas should be represented graphically, numerically, and symbolically. Also debated was the theory that calculus courses should teach students the big ideas of calculus rather than some arbitrary collection of manipulative skills. A student's ability to read and write about mathematical ideas is essential, and the instructor should emphasize the use of real-world applications and interdisciplinary projects to motivate learning calculus ideas (Beers, 1991; Child, 1991; Cole, 1993; Dubinsky & Schwingendorf, 1991; Hoft, 1991; Small, 1991; D. A. Smith & Moore, 1991). General agreement about what to change centered on the modes of instruction and use of computing technology, along with an increased focus on conceptual understanding and decreased attention to symbolic manipulation. The major theme shared across the various conferences was that the use of computing technology's graphing and symbol manipulation capabilities could provide greater access to multiple representations, along with greater opportunity for a problem-solving focus. This increased access could create changes in the traditional calculus curriculum regarding what instructional goals would be feasible and what instructional focus should be emphasized (Ferrini-Mundy & Graham, 1991; Kasten, 1988; Kolata, 1987; Tucker & Leitzel, 1995).

In order to support the movement to reform calculus instruction, the National Science Foundation (NSF) provided financial backing for the development of various initiatives (Jost, 1992; Kasten, 1988). Between 1988 and 1990, NSF awarded financial support for 43 different calculus reform projects, totaling nearly seven million dollars (NRC, 1991; Tucker & Leitzel,

1995). Several calculus reform programs were proposed, such as the Harvard Calculus Consortium curriculum, the Calculus and Mathematica project at the Ohio State University, and the Project CALC at Duke University. Although these initiatives advocated the use of a variety of teaching approaches and philosophies, they all emphasized the use of computing technology as a vehicle to implement the reform movement's goals for learning and teaching calculus (Cole, 1993; Porzio, 1994). Many reform calculus courses used various computing tools to stress visual and numerical representations in addition to the traditional symbolic representations (Brown, Porta, & Uhl, 1990; Graves & Lopez, 1991; Heid, 1988; Muller, 1991; Ostebee & Zorn, 1990; Small, 1991). Although the majority of calculus reform projects were not adopted very far beyond their local colleges and universities, collective efforts managed to create a noticeable shift in calculus instruction. This shift has been the driving force in reform of collegiate curricula at all levels (Hillel, 2001; Knight & Trowler, 2000).

Within the calculus reform movement, there have been intensely heated debates over various issues. A major focus of the debates has been to determine the benefit achieved by using computing technology and how much emphasis should be placed on a student's previous algebraic knowledge. A wide variety of factors motivated the creation of the reform initiatives. Some of those factors were based on an altruistic desire to make calculus ideas and concepts more understandable for a broader range of students. Other factors focused more on practical considerations regarding what calculus topics need to be taught, reflection on the type of mathematics that is suitable in an information age, and a growing aspiration to understand how students learn calculus concepts (D. A. Smith & Moore, 1991). Although calculus reform initiatives have been both praised and condemned in various studies (Cipra, 1988; Hillel, 1993; Peterson, 1987; Small, 1991; Stacey, Kendal, & Pierce, 2002; Wilson, 1986), a careful analysis

of the research findings provides ample evidence for implementing the proposed suggestion of incorporating computing technology into calculus instruction.

### **The Calculus Reform and Computing Technology**

The calculus reform initiatives implemented a wide range of pedagogical methods for the integration of computing technology. Some reform projects assigned computer projects to be completed outside of class, whereas other projects demonstrated various technological tools and examples of ways to use them to enrich lectures. Still other projects used software as a primary means for delivering calculus concepts to the students. A considerable body of research conducted over the last 30 years, in contrast, supports the contention that conceptual understanding of calculus concepts is enhanced through use of multiple representations (numerical, graphical, and symbolic) while linking the representations using computer or calculator technology (Heid, 1988; Porzio, 1994; D. A. Smith & Moore, 1991).

Some of the commonly cited advantages of using multiple computing approaches in calculus instruction include emphasizing the usefulness and relevance of mathematics (Ferrini-Mundy & Graham, 1991; Kolata, 1987; Small & Hosack, 1986); developing cost-effective methods for teaching and learning mathematics (Anderson & Loftsgaarden, 1987; Schrock, 1989; Ubuz & Kirkpinar, 2000; Zorn & Viktora, 1988); employing multiple-representations to support intuition and concepts (Small & Hosack, 1986; Zorn, 1986); and enhancing the ability to seek counterexamples (D. A. Smith & Moore, 1991). Additionally, the use of multiple computing approaches allows instructors to enhance the exploration of complex problems and mathematical ideas (Groves & Zemel, 2000; Schrock, 1989; Small & Hosack, 1986; Tucker, 1990) by creating more interesting exercises with real-world data (Ganguli, 1992; Porzio, 1999) and facilitating discovery approaches (Schrock, 1989; Porzio, 1994, 1999; Ubuz & Kirkpinar,

2000). Ultimately, instructors can use technology to enliven courses and get students more involved (Ganguli, 1992; Porzio, 1999; Tucker, 1990; Zorn & Viktora, 1988) while also motivating them to assume more responsibility for their learning (Heid, 2002; Porzio, 1999; D. A. Smith & Moore, 1991; Ubuz & Kirkpinar, 2000). Although some of these goals may be achieved without technological tools, the tools are already available and accessible.

Technological advances in computing make it easier to teach mathematics concepts without prior or concurrent mastery of algorithms (Heid, 2002), and to construct a meaningful concept image of doing mathematics proofs (Dubinsky & Schwingendorf, 1991).

### **Statement of the Problem**

Despite the presence of an ever-increasing number of research findings, the efforts of dedicated collegiate mathematics instructors, and the growing access to technology, computing technology has not become an integral part of calculus classes. The role of technology in teaching and learning calculus has been, and is still, a very heated topic of debate. In the 1980s, a small fraction of instructors adopted computing technology, developing innovative ways to incorporate it into their teaching. Many instructors, however, resist using computing technology in their classrooms; others have vacillated between using computing technology and not using it. Simply placing technology in calculus classes, without a plan or strategy for incorporation and implementation, has not been (and will not be) productive in most classes. Adopting computing technology successfully involves more than the instructor's ability to use it as a tool; successful adoption requires changing the pedagogical practices of instructors (Park, 1996; Roschelle, Kaput, & Stroup, 2000). The integration process itself reveals and embodies what some instructors of calculus want to emphasize or avoid. Instructors are compelled to examine their feelings about technology as a legitimate means to an end by considering questions such as:

What do students really need to learn? And have paper-and-pencil skills remained relevant in today's world?

Research studies have shown that an instructor's conception of the importance of computing technology is a critical determining factor in the effectiveness of its implementation in the classroom (Groves & Zemel, 2000; Roblyer & Knezek, 2003; D. L. Rogers, 2000). Mathematics instructors' understanding regarding how students learn and their personal conceptions of what constitutes positive instructional practices influence the way they use computers in the classroom (Santucci, 2007; Simonsen & Dick, 1997). Any attempt to implement policy changes and adjustments, therefore, must be viewed in terms of the instructor, who ultimately controls how the technology will be used in the classroom. The successful execution of changes in the way that undergraduate mathematics is taught depends largely on individual instructors and their collective actions. Without instructor involvement, all computing technology integration initiatives will fail. With an instructor's enthusiastic support, great benefits can be realized for both the students and the educational institution. In order to achieve a successful integration of computing technology into classrooms, there is a need for a more complete understanding of the most constructive ways to promote change among mathematics instructors, with a particular focus on calculus instructors.

Over the past 10 years, I have made repeated visits to several calculus classes to observe the use or lack of use of various types of computing technology. Additionally, I have initiated informal conversations on the subject with several of my peers. Overall, I have been shocked and dismayed to see the widespread absence of computing technology in calculus classes. I have consistently found that very few calculus instructors exhibit an enthusiasm or a willingness to learn about the integration of computing technology into their instruction. Although there are

instructors who believe that computing technology is the gateway to the empowerment of students, there seem to be far more who are highly skeptical of the benefits to be gained from using that technology. I have also encountered colleagues who seem to be threatened by the incorporation of computing technology into my classroom instruction. In conversations with other collegiate mathematics instructors, I have discovered that their attitudes toward using computing technology cover a very broad spectrum, encompassing everything from reverence to indifference to scorn.

As my interest in calculus instructors' conceptions of teaching with computing technology grew, I began to look for related research literature. Despite the central role of the instructor in the educational applications of computing technology, relatively little research has been conducted on how and why collegiate mathematics instructors use (or do not use) that technology. In addition, I was unable to find a research study on collegiate mathematics instructors' conceptions of teaching and learning mathematics. Most research about computing technology has focused on its impact on student learning; little attention has been given to the instructors. Numerous research studies of collegiate mathematics education have focused on students: how they learn, what attributes enhance their success (or lack of it), what misconceptions students bring to specific content areas, and learning issues concerning gender and ethnicity. Interestingly, I was able to find a great deal of research on methods of teaching calculus by using computing technology. I was also able to find research that demonstrates the ways that learning calculus in a technologically integrated classroom results in a significant and positive change in students' attitudes towards mathematics (Laurillard, 1993; Rahilly & Saroyan, 1997; Santucci, 2007). Despite the overwhelming amount of research indicating the advantages of using computing technology in calculus instruction, however, almost none of the research

provides insight into instructors' apparent unwillingness to integrate that technology into calculus courses. As a result, there continues to be a gap in our knowledge and understanding of the factors and processes that mathematics faculty members use when choosing whether or not to adopt computing technology in the classroom.

Framing the context for technology integration in undergraduate mathematics education requires uncovering the diversity of instructors' purposes, goals, interests, and values. As Hodas (1993) noted, "Real change happens within organizations when employees, who are presented with a new way of working, shift their attitudes and beliefs about how work gets done" (p. 181). Therefore, I decided to conduct a study to examine the positive and negative steps taken by mathematics instructors when choosing whether or not to use computing technology in teaching calculus. Ultimately, my goal was to provide insight into the rich detail involved in the way a faculty member seeks or resists change related to the integration of technology into methods of instruction. My initial investigation of this topic indicated that several major factors influence instructors' decisions about using computing technology in calculus instruction. Exploration of those influences, and an examination of the interactive web of instructors' conceptions, may be able to provide a foundation for the development of successful professional programs aimed at promoting technology integration. If mathematics educators are to understand how computing technology is diffused and what kind of adaptation is needed, they must understand the conceptions of calculus instructors, as those beliefs reveal the instructors' real reasons for use and nonuse of computing technology (Ertmer, 1999; Kersaint et al., 2003). As Kilpatrick (1994) pointed out: "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).



By looking beyond an individual instructors' personal view of computing technology, the collegiate mathematics community will benefit from a deeper understanding of the following questions: Do instructors use computing technology in teaching calculus? If so, why? In what ways do instructors use computing technology to teach calculus? What happens when they do? Why do instructors choose not to use computing technology? What factors influence the implementation of computing technology at the collegiate level? The struggles, challenges, and successes encountered by calculus instructors when attempting to integrate technology into the classroom are important. Such information can become the foundation of effective professional development strategies designed to ease the transition through the technology integration process.

In the present study, my ultimate goal was to improve the way that undergraduate mathematics is taught, with a specific focus on the instruction of calculus. In order to achieve my goal, it was critical to understand the nature of collegiate calculus instructors' views and attitudes with respect to the use of computing technology. Although I may not have uncovered all of the aspects of this complex topic, I do hope to have shed significant light on effective ways to integrate the use of computing technology into collegiate level mathematics education. The findings of this study may enable a better understanding of the characteristics that influence the ability of instructors to integrate computing technology effectively into the classroom. My aim was to develop a vision of computing technology integration and a program focused on addressing patterns of change.

### **Research Questions**

This report, therefore, is the account of my research efforts to understand *why* calculus instructors use or do not use computing technology in their calculus classes. To understand the

*why* or *why not*, it was necessary to examine the ways in which instructors currently use computing technology as well as their previous experiences with various types of technology. My goal was to understand why instructors do what they do—to describe and interpret how their conceptions inform and shape the way that they choose to teach collegiate level calculus. The method I used in conducting this research was to examine the categories, themes, patterns, and implications of using computing technology. In particular, this study addressed the following research questions:

1. For instructors using computing technology to teach calculus,
  - a. What are their conceptions of mathematics and learning mathematics?
  - b. Why do they use computing technology?
  - c. How do they use computing technology?
2. For instructors who never use computing technology to teach calculus,
  - a. What are their conceptions of mathematics and learning mathematics?
  - b. Why do they not use computing technology?
  - c. How do they teach calculus without using computing technology?
3. For instructors who once used computing technology to teach calculus,
  - a. What are their conceptions of mathematics and learning mathematics?
  - b. Why do they no longer use computing technology?
  - c. How do they teach calculus without using computing technology?
4. How do instructors in community colleges and universities differ in their teaching of calculus with or without computing technology?

To investigate these research questions, I chose six mathematics instructors based on their response to an initial technology survey. The research participants included three from a

research university and three from a community college. The selection of participants was targeted at three types of instructors, one from each institution: two who were currently using technology in their calculus classes, two who had never used computing technology in the classroom, and two who had used it in the past and had mixed feelings about its use in their calculus classes. To uncover their conceptions regarding the use of computing technology in calculus instruction, I conducted a series of interviews with each research participant. In addition, I carried out observations that focused on their classroom methods and instructional style.

## CHAPTER 2: LITERATURE REVIEW

### Conceptions

In this study, a *conception* was defined as personal assessment of one's knowledge, beliefs, values, and concepts in a given domain. Many researchers have described the need for research into the conceptions and practices of higher education faculty members, as teaching practices are influenced by their conceptions about teaching and learning (Pajares, 1992; Pehkonen & Törner, 2004; Pepin, 1999). Gaining an understanding of instructors' conceptions and of how those conceptions influence their perceptions and actions is critical to improving teaching practices since the conceptions held by faculty members significantly influence the educational outcomes of students. This influence can be either explicit or implicit, reflected in the manner in which the instructor seeks change, delivers instruction, and defines classroom success. Furthermore, the formation of and adherence to a particular set of conceptions can serve to give faculty members a sense of constancy, reinforcing both the self and group identity (Nixon, 1995). As reform efforts to integrate technology take hold, resistance may be more closely tied to the changing group dynamic than to the introduction of a specific technology. It is important to maintain an awareness of these underlying issues, since they have the potential to become barriers that would prove difficult to negotiate. As Kreber (2000) succinctly put it:

The new policy seeks great change in knowledge, learning, and teaching, yet these are intimately held human constructions. They cannot be changed unless the people who teach and learn want to change, take an active part in changing, and have the resources to change. It is, after all, their conceptions of knowledge, and their approaches to learning and teaching that must be revamped. (p. 76)

To make the issue more complicated, conceptions often include feelings based on subjective knowledge. Several researchers note that conceptions are not easily observed; rather, they must be inferred (Pajares, 1992; Pehkonen & Törner, 2004) since individuals frequently do not have an awareness of their own conceptions. Because they are often unconsciously held, conceptions must be inferred from individuals' demonstrated actions, statements, and behaviors (Pajares, 1992; Rokeach, 1968).

### **The Formation of Conceptions**

According to Rokeach (1968), direct and indirect experiences and observations form conceptions of individuals differing in consideration to the social and physical world. These conceptions are somehow organized “into architectural systems having describable and measurable structural properties which, in turn, have observable behavioral consequences” (p. 1). Other researchers suggest that conceptions may or may not be logically formed, that they vary in strength, and that the difficulty of changing one's conceptions will be dependent on how strongly they are held (Windschitl & Sahl, 2002). According to Windschitl and Sahl (2002), conceptions can be descriptive, inferential, or informational. Descriptive conceptions emerge from observations; inferential conceptions are a result of inferences made from those observations; and informational conceptions are those gathered from outside sources.

According to Rokeach (1968), conceptions have three distinct components: cognitive, affective, and behavioral. The cognitive component of conceptions represents an individual's knowledge and experience, and is held with varying degrees of certitude. The affective component of conceptions is the feeling or emotional reaction surrounding the conception. This emotional reaction prompts individuals to form an internal judgment of something as negative or positive, good or bad. The behavioral component of conceptions reflects an individual's

predisposition to act in certain ways, based on a combination of both the cognitive and affective components. Rokeach believed that our conceptions of one area of thought are connected to many of our other connections, that they impact and modify each other and that each conception has bearing on our other conceptions. The contrasts of the conceptions' interconnectedness are contained in four categories. First, the shared conceptions about existence and self and conceptions that are unshared in this regard. Second, conceptions that are existential versus ones that are non-existential in nature. The third contrast is the conceptions that regard the individual's personal preferences. And forth, conceptions that are derived and those conceptions that are not.

The four contrasting implications between the interconnectedness of conceptions begins with a stipulation that when a conception is shared between group members, the functionality and connectedness are stronger than the conceptions that are held by individuals. In contrast to this, the second viewpoint states that when one's "existence and identity" (Rokeach, 1968, p. 5) are more intertwined into their conceptions, their existential conceptions are stronger than those who fail to see a connection of their existence and identity to their conceptions. The third viewpoint suggests that conceptions are defined and shaped by an individual's personal preferences alone, and the individuals that exemplify this connection form conceptions with less function and influence than other, stronger conceptions. The forth viewpoint posits that the strongest, most functional conceptions are those conceived out of experience directly, rather than the derived conceptions that are conceived out of indirect reference to another individual's conceptions.

According to Pajares (1992), the most difficult conceptions to modify are those derived from direct experience and observation. These conceptions become intertwined into the

personality and views of an individual into conception systems. The structure that is built dictates whether or not new ideas will enter the conception system or be rejected, based on whether or not the new ideas are consistent with previously formed conceptions. Some of these conceptions may join the system, however, and as a result the individual holds conflicting conceptions. As expressed by T. F. Green (1971), conceptions are held in “clusters, more or less in isolation from other clusters and protected from any relationship with other sets of conceptions” (p. 48). This protection of conflicting conceptions may explain why higher education faculty might demonstrate inconsistencies in what they profess to believe and the way they actually act.

### **Conceptions as Impediments to Faculty Change**

In a 1986 study, Schoenfeld noted that conceptions relating to acceptable classroom instruction are complex, and are often a result of “an intricate interaction of cognitive and social factors existing in the context of schooling” (p. 45). According to Schoenfeld (1986), conceptions are formed through an individual’s experiences and are heavily modified by the culture of the institution’s classroom setting and curriculum. In the studies of Ball and Cohen (2000) and Barnett (2011) that focused on the connections between conceptions and practice, they note the conceptions of instructors and the implementation of teaching practices are strongly connected to each other, and have strong bearing on the conceptions they have for student learning. Understanding the conceptions held by higher education faculty becomes extremely important, given that any new conception introduced to faculty members will be filtered through the lens of previously held conception structures and experiences (Borko & Putnam, 1996). Ball and Cohen (2000) stated:

In ways not well understood, the odyssey [for improving teaching] probably entails revising deeply held notions about learning and knowledge and reconsidering one’s

assumptions about students and images of oneself as a thinker, as a cultural and political being, as a teacher. (p. 105)

In higher education, the enculturation into a particular academic discipline makes the implementation of reform initiatives difficult to attain through its dominant role in the development of a faculty member's conceptions (E. L. Boyer, 1990). Enculturation into a particular discipline leads individuals to adopt conceptions generally upheld by the reference group. Conceptions that are created and fostered by the discipline will "generally endure, unaltered" (Pajares, 1992, p. 316) unless they are deliberately challenged. Faculty members who receive little to no training in teaching methods are generally influenced by the "guiding images" of their profession (LaBerge, Zollman, & Sons, 1997), which then ultimately influence their classroom practices. The conceptions held by mathematics faculty members are tacit and often difficult to change (Pajares, 1992). The faculty involvement in new experiences can either lead to the reinforcement of existing conception structures or result in the development of new conceptions that challenge existing conception systems.

Previously instructing purely through constant lecture, Nixon (1995) recounted his experience as a faculty member of a higher education institution who transitioned to a small-group learning format, an opportunity that gave him the freedom to observe students on a personal level as he walked around the room among his small groups. Although Nixon saw strong evidence that he was adequately teaching in this manner (some students demonstrated "intelligent remarks" regarding the subject matter), he began to postulate that this merely inflated his ego and led him to assume his techniques would be universally effective for all students. As he came to this realization, he reflected that he may have been doing something wrong in his instruction, or perhaps that he neglected to include something into his lecture that he should have. As he said, "I always feel a twinge of guilt in using the small-group method, for I have



been accustomed to identifying teacher-speaking with student learning. Doesn't a singer sing, a preacher preach, and a teacher teach?" (p. 1028). Although Nixon made no explicit mention of his experiences as a student, one can assume that his own education and training involved the dominant use of the lecture method. Lecture is what teachers do, and that is how students learn. For Nixon, this deviation from what he *ought to do* as a mathematics instructor yielded certain feelings of guilt and a lack of adherence to what the profession called for. Although Nixon recognized the effectiveness of small-group activity, he still felt residual guilt for not following the precepts of his profession.

### **The Formation of Mathematics Professors' Conceptions**

The method by which faculty members shape their instruction, especially in terms of conceptions of learning and applying pedagogy (J. M. Boyer, 1997), is greatly affected by the instructors' processes of disciplinary enculturation. These conceptions are grounded in an instructor's experiences from early schooling (grades K-12) to higher education (graduate school), the latter of which being where the instructor experienced more formative and specific disciplines. Experiences in the classroom, which provided social interactions with students and colleagues, further shaped these conceptions. The discipline of mathematics is defined for each instructor by the conceptions formed from an enculturation into the discipline, beginning with their introduction to school and ending where they begin to interact with their peers within not only the educational, but also social confines of mathematics with their peers consisting of students and colleagues alike. Hersh (1997) noted:

One's conception of what mathematics is affects one's conception of how it should be presented. One's manner of presenting it is an indication of what one believes to be most essential in it. The issue, then, is not, 'What is the best way to teach?' But, 'What is mathematics really about?' (p. 13)

A mathematics instructor's conceptions of the subject are an amalgamation of the individual's concepts, conscious and subconscious, combined with the individual's understanding of the rules, meanings and preferences within the discipline. The instructor's individual understanding of mathematics forms in the individual the teaching process he or she chooses to implement in the classroom (Entwistle, Skinner, Entwistle, & Orr, 2000; Hersh, 1997). The process of deciding how to implement teaching methods is dictated by the individual's conceptions that are formed.

Several research studies have examined various ways in which the conceptions of mathematics instructors influence their actions in the classroom (Alsina, 2001; Pepin, 1999; Thompson, 1984; Thomas & Holton, 2003; Wilson, 1986). Ernest (1989) took the research even further when he differentiated and defined three key components that shape the views of mathematics instructors. He labeled the resulting teaching styles as the *instrumentalist*, the *platonist*, and the *problem solver*. Ernest pointed out that each viewpoint is distinguished by a particular set of conceptions about the nature of mathematics. These conceptions lead to a particular way of defining the role of the instructor, which then leads to a distinctive style or method of teaching in the classroom.

According to Ernest (1989), the *instrumentalist* views mathematics as "an accumulation of facts, rules and skills to be used in the pursuance of some external end. Thus, mathematics is a set of unrelated but utilitarian rules and facts" (p. 250). The main goal of instruction, according to the instrumentalist, is achieving a solid mastery of specific skills and proper performance. The *platonist* view regards mathematics "as a static but unified body of a certain knowledge. Mathematics is discovered, not created" (p. 250). Platonists, according to Ernest, have a more absolutist view than the other two types. Ernest states that an absolutist view of mathematics

does not focus on “describing” mathematics or mathematical knowledge. Platonists view mathematical knowledge as pure and timeless, even superhuman. Mathematics is viewed as isolated and unaffected by the world at large, which gives it universal validity; it is both value-free and culture-free (p. 2). The platonist is concerned with developing conceptual understanding and providing unified knowledge of mathematics. The *problem solver* sees the study of mathematics “as a dynamic, continually expanding field of human creation and invention, a cultural process. Mathematics is a process of enquiry and coming to know, not a finished product, for the results remain open to revision” (p. 250). The problem solver defines the role of instructor as a facilitator whose goal is to ensure his or her students are confident problem posers and solvers. These conceptions about mathematics, according to Ernest, are more likely to be “implicitly held philosophies” (p. 250) that become automatic over time rather than consciously held views.

A series of case studies from Ball and Cohen (2000) of teaching mathematics showed that the conceptions of teachers affected their perceptions and actions towards changing the way that they taught mathematics. Among teachers, the nature of mathematics and the way it is learned differed in their conceptions, and as a result, influenced what material was taught and the implementation of instruction. Instructors’ personal conceptions reflected in their instructional practices, and especially involving mathematics, this reflection was discovered through research studies and findings (LaBerge et al., 1997; Pepin, 1999). Ball and Cohen (2000) note:

Teachers’ conceptions and conception systems are grounded in their personal experiences and hence, are highly resistant to change. Typically, though, these experiences are a byproduct of the school context in which they work. If school practitioners are not given outside information about this context that can help them be critical of their past experiences or about new contexts that portend some new experiences entirely, then the risk is that research will actually reify that context rather than reform or restructure it. (p. 27)

In some instances, members of a faculty performed in contrasting ways to their claimed conceptions. In a study of the conceptions of mathematics professors, 26 faculty members were selected for observation in the classroom following an interview about their conceptions. Some of the faculty members demonstrated a traditional classroom of lecture and note-taking, although they implied in their interviews that they would like to implement more modern techniques and activities, speculating that students in lower level classes might not be ready to perform these activities, while also making note of the “negative conceptions and expectations related to mathematics” (LaBerge et al., 1997, p. 15) that undergraduate students hold.

### **Influences Shaping Mathematics Faculty Members’ Conceptions**

According to Wegner (1998), Calderhead (1996) and Dunkin (2001), the conceptions of teachers in the mathematic field affect their interpretations of teaching methods and interpretations of the content, which drastically affects classroom activity. Over the span of a career of any given faculty member, direct experience and social influence shape their conceptions and in turn, what is considered to be valid knowledge (Pajares, 1992; Pehkonen & Törner, 2004). Conceptions between faculty members can drastically vary, as faculty members may not experience the same events during schooling, or one faculty member may be more impressed by a particular event than another. In spite of literature suggesting that a teacher’s conceptions about mathematics are not related in a simple cause-and-effect way to his or her instructional practices (Pepin, 1999), the research findings indicate that there is often a considerable level of agreement between conceptions and actions (Abelson, 1979; Movshovitz-Hadar & Hazzan, 2004). As a result, the parameters established by faculty members’ conceptions of the discipline serve as a constraint on the future opportunities of students.

According to Ernest (1989), the expectations and norms of an academic institution and the actual experiences of a faculty member's classroom defined the preferred models of teaching and learning mathematics. These two factors often conflict and can divide an instructor's intentions from his or her behaviors. Some instructors adopt methods more aligned with an institution's expectations due to the social context of students, faculty members or administration, even when those methods contrast with the instructors' personal conceptions. Socialization is further defined by the institution's curriculum, student placement assessment, and the administration's perception of mathematical skill acquirement.

Faculty members are not always fully aware of their mathematical conceptions or the way that they may act upon them, and as a result, Alsina (2001) noted that the conceptions of faculty members are rarely challenged or seen. From institution to institution, conceptions became self-incorporated as a result of personal experience and further defined by the institution's other faculty members. Even though the conceptions cannot be easily seen or evaluated, they heavily impact the methods of an instructor of any given institution.

Some mathematics instructors emphasized a desire to require students to perform activities out of the classroom as well as out to demonstrate real-world application of problem-solving skills and critical thinking, but revealed that achieving this was unrealistic due to the fact that students "haven't been taught to be self-sufficient" (LaBerge 1997 p. 12). The faculty members could implement these desired methods and techniques if the previous schooling of their students was effective enough, but lack of appropriate prior instruction instead drove a wall between them and the students.

The age of faculty members reflect the amount of time spent in a field as well as an indication of how solidified a persons' conceptions would be. The longer a conception exists in a

person's mind, the more deep-rooted it will be. Because of these firm conceptions, successful academic reform may require a complete modification in the conceptions of older faculty members. Wilson (1986) explains:

To affect a change of the magnitude the system [demands] is to literally ask a person who has spent his adult life becoming the person he is to become someone else. No one throws over his identity easily, especially when a natural hardening of the professional arteries and a certain level of conservatism has set in. (p. 201)

In order to implement successful reform, consideration should be taken in regards to the amount of resistance that will be encountered among faculty members, especially in the case of senior members. Some faculty members could perceive technology integration with contempt, anxiety or doubt, although it may manifest as cynicism and mockery. If the integration is described as supplemental to teaching practices rather than fixing a perceived problem, some of the reluctant instructors may be more open by decreasing their anxieties.

### **Higher Education Culture and Technology Integration**

As a higher education facility attempts to integrate technology into the curriculum, the perspectives of the faculty are shaped by the institution's culture, and have a strong influence on the implementation of technology in the classroom (J. M. Boyer, 1997). Providing education is a highly normative activity, so lasting change can require a cultural transformation along with the active involvement of faculty. Several research studies have demonstrated that the instructors are the primary impetus for technology integration in the classrooms of higher education institutions. Additionally, the integration process is facilitated when the faculty of an institution is open to the inclusion of technology in the classroom (Ely, 1999; Ertmer et al., 2001). Thus, technology integration initiatives in higher education must be designed as collaborative undertakings rather than predefined policies. For technology integration to be successful, the instructors must first

see a need for the use of the new technology and significant benefits to be gained from its implementation. This change in the institutional culture is necessary to overcome the resistance by faculty members regarding adjusting their beliefs, behaviors, and teaching styles.

### **What Is Higher Education Culture?**

In addition to being scholars, the members of a university faculty are also teachers. There are, however, significant differences in the way that elementary or high school teachers view their roles, and the way that university professors do (Cox, 2001; Hativa, 1998; Kember, 1997). Surprisingly, many higher education faculty members consider themselves “a breed apart from school teachers. ... [Many professors] hardly consider themselves ‘teachers’ at all, instead visualizing themselves more as a member of their discipline” (Kember, 1997, p. 255). In their study of six higher education institutions, Hativa, Barak, and Simhi (2001) found that while the higher education culture encouraged autonomy, disciplinary scholarship, and research, it was also very steeped in tradition and resistant to change.

The higher education culture can be either the catalyst or an inhibiting factor when implementing changes because the faculty members strive for positive reinforcement and have a strong emotional attachment to their organization through its culture (Kane, Sandretto, & Heath, 2002; Kline, 1977; Knight & Trowler, 2000). The management style of many universities and colleges can be described as a "loose-tight" principle: the individual creativity and innovation of a faculty member is fostered, so long as the faculty member's behavior properly aligns with institutional values. If the faculty member's behavior defies the institution's values, the institution “tightens” in order to guide the faculty member's behavior back to the accepted norms (Nixon, 1995). According to Kluckholm (1962), the higher education culture can be defined as

persistent patterns of norms [of behavior], [shared] values, practices, beliefs, and assumptions that shape the behavior of individuals and groups in a college or university

and provide frame of reference within which to interpret the meaning of events and actions on and off the campus. (p. 245)

*Shared values* are important concerns and goals shared by the majority of people in a group. Those values tend to shape overall group behavior, and they often persist over time. Even when group members change, the values tend to remain stable and are adopted by new group members as they fully assimilate into the group. *Norms of behavior* can be defined as the common or pervasive ways of acting that are found in a group, as well as the behavioral expectations of members within the culture. Those behaviors persist because group members teach the practices to new members by example, rewarding those who fit in and sanctioning those who do not.

From universities and colleges throughout the United States, 800 faculty members were selected for a study (Braxton, Bayer, & Finkelstein, 1996) that identified the behavioral norms of teaching styles within an institution. The first behavior identified was the interpersonal relationships of instructors between their students and their colleagues, especially regarding their feelings and opinions. The second was the grounding of fair grading practices in outstanding academic performance. Participants also cited the moral behavior of faculty as the third behavioral norm, in regards to their interactions with students and other classroom practices. The final behavioral norm of instructors was identified as proper planning for the class, citing organization and adequate preparation. Understanding these teaching norms is important, because they help to realize a reflection of culture within a faculty, as well as the way in which the instructors shape their teaching styles. As teaching is the primary activity of universities and colleges, a guide to professional behaviors can be attained through understanding these behavioral norms. The faculty members' conceptions of teaching and learning are formed early



and shaped within the framework of their culture and experiences as students (Rahilly & Saroyan, 1997), and the higher education culture plays an important role in reform initiatives.

Looking beyond shared values and behavioral norms, several researchers have also proposed that faculties actually operate within four overlapping, yet distinct, cultures: *the academic profession in general, the individual discipline, the specific institution, and the institutional type* (J. M. Boyer, 1997; Miller, Binder, Harris, & Krause, 2011; K. B. Smith, 2000). These studies emphasize the importance of the culture of the particular discipline on the development of a teacher's conceptions and behaviors, noting that the faculty members have spent years being socialized into their discipline of choice. A student experiences the beginning of socialization during the formative years of his or her education, and grows stronger as he or she continues along the professional path. As a student establishes a sense of belonging, the student strengthens self-identity among peers within the discipline (E. L. Boyer, 1990; Rahilly & Saroyan, 1997; Richardson, 1996; Sporn, 1996). The theories and methods regarding the specific academic area "become paradigms that structure the way their members see the world" (p. 156) according to J. M. Boyer (1997). Several researchers note that socialization of faculty members are within an "academic discipline" rather than a "teaching profession." Boyer (1997) and Grubb (1999) assume that as an individual's mastery of the subject evolves and adapts, so will the individual's teaching skills. In order to implement change to methods of teaching information, an instructor must accept that the changes are consistent with the way instructors are growing and changing. The instructors must realize that previous methods are no longer sufficient, and accept and implement a shift in teaching methods.

## **How Does the Culture Affect Technology Integration in Higher Education?**

In higher education, the adoption of new technological innovation appears to be a function of the financial resources available, the perceived value that faculty ascribes to the innovation, and the extent to which faculty members communicate with other adopters of the innovation (K. B. Smith, 2000). However, different funding structures for departments, support from senior faculty members, and influences of a unifying group identity among colleagues all contribute to the acceptance of technology within a specific discipline. The atmosphere in the discipline plays an especially important role in technology integration by faculty because each department designs and manages its technology integration programs in a manner that is consistent with the policies and mission under which it operates (Surry & Ely, 2006; Surry & Land, 2000). Thus, when a department sets out on the journey of technology integration, it must uncover and then address the invisible assumptions and premises on which its decisions and actions are based.

The department and instructors within demonstrate a commitment to improving teaching methods, serving as a catalyst towards technology integration. Two conditions must be met in order to successfully integrate technology: a consideration for the environment of the institution, regarding knowledge of the benefits of computing technology and the faculty members' previous prejudices that have been constructed (McAlpine & Gandell, 2003; Sporn, 1996). When an atmosphere of support and encouragement are established within every level of the institution from departments to individuals, successful integration can occur. The new technologies are "adopted by the community through the discourse of its members and the evolution of practice over time" (D. L. Rogers, 2000, p. 24). Thus, the acceptance and diffusion of new technology

into a culture occur more rapidly when the culture is open to change and continuous improvement.

Second, an environment must be created that fosters collaboration between all participants; faculty-to-faculty influence, in regard to the adoption of instructional technology, is important to the process of change and cannot be underestimated (McCracken, 2008).

Opportunities for the faculty to observe models of integrated technology use should be provided to allow the faculty to reflect on and discuss their ideas with peers, and to allow collaboration between the faculty on meaningful projects as they test new concepts regarding teaching and learning with technology. Part of the challenge for higher education institutions attempting to integrate technology in the classroom is to create a culture that values and develops faculty interest in teaching with computing technology. An enabling environment that explores new practices and provides incentives for taking risks in regards to improving learning and teaching must be created for the process. At the same time, the resistance to change must be met with patience and understanding. According to a variety of studies, the essential components are peer collaboration and faculty mentoring that must be implemented in order to successfully integrate technology into the classroom (Durrington, Repman, & Valente, 2000). Furthermore, the importance and influence of interpersonal networks on the adoption of innovations by individuals have been noted in several studies (Durrington et al., 2000; E. M. Rogers, 1995).

In his 1995 book on the mechanisms of technology diffusion, E. M. Rogers discusses the concept of homophily in communication networks. *Homophily* refers to the tendency of individuals to associate and bond with others who are similar to themselves. Rogers asserts that homophilic communication—defined as the degree to which pairs of individuals who communicate are similar—can limit the spread of an innovation to individuals within the same

network. This observation was supported in a study by Durrington, Repman, and Valente (2000) in which the adoption of technology by a university's faculty was hindered by lack of communication between friendship networks.

As noted by Schifter (2003), it can be difficult to attain the creation of communities that collaborate within the faculty of a university setting, a type of faculty that creates a schism of the instructors by motivating for the strong scholastic performances of individuals rather than collaborations, especially when strong individual performance is recognized and rewarded. The participants in Schifter's case study indicated that core values in their academic institutions might affect their use of technology in classroom instruction. The faculty members expressed support for a conservative approach to the diffusion of technology in education and stated that instructors should not be pushed to use technology, unless it was essential to the content of the course. Interestingly, even the faculty members who were already using technology in their instruction thought that the professional autonomy of others who did not use technology must be maintained and respected.

### **Community College Culture and Institutional Type**

Vast differences exist among the cultures of higher education institutions. Traditions, history, resources, styles of leadership, reward structures, expected teaching load, physical space, collegial relationships, and the process of governance are some of the many areas of potential differentiation among colleges and universities (McClenney, McClenney, & Peterson, 2007). The degree of emphasis placed on teaching norms varies across institutions according to the value that is placed on teaching (Braxton et al., 1996). The main source of these differences can be attributed to the institution's mission and to the student and faculty populations. Unlike universities, community colleges are rarely cited for academic excellence, as that distinction is

most frequently ascribed to prestigious research institutions (Ehrenberg & Zhan, 2005; Grubb, 1999). As open access institutions, comprehensive community colleges provide educational opportunities to a wide spectrum of students. The mission of the community college is to provide a stepping stone into higher education. Accordingly, community colleges give individuals living in communities that do not have access to larger universities the opportunity to further their education, while also providing educational opportunities to traditionally low achievers (Hagedorn, Maxwell, Cypers, Moon, & Lester, 2007).

Community college students are infamous for being underprepared, a trait that provides a substantial challenge to the mission of the community college, the achievement of student objectives, and the classroom practices of faculty members (Feldman, 1987; Forest, 1998; Frost & Teodorescu, 2001; Grubb, 1999). The National Center for Education Statistics (NCES, 2004) indicated that 98% of community colleges offered remediation in reading, writing, and mathematics, with 42% of first-year students enrolled in at least one precollegiate course. In mathematics classes offered, community colleges differ significantly from universities. For example, in a study for the American Mathematical Association of Two-Year Colleges (AMATYC), Serow, Van Dyk, McComb, and Harrold (2002) found that the percentage of student enrollment in mathematics courses at community colleges in 2005 was as follows: Developmental Basic Skills Mathematics (57%), Precalculus (19%), Calculus (6%), Statistics (7%), and other mathematics courses (11%).

Student population and the expectations of students are the second major source of difference between colleges and universities. Community colleges differ from four-year schools in their student population regarding age, gender, race, enrollment status, preparation and objectives (Diel-Amen, 2011; McClenney et al., 2007). Eagan and Jaeger (2009) described the

students of community colleges as older with a balance towards women and racial minority groups, that they are attending part time, and are more likely to be the first person to attend college in their families when compared with four-year schools. Ryan (2004) noted the following demographic characteristics of community college students: The average age was 29; 36% of the students were 18–21 years old, 15% were 40 years or older; 58% were women; 33% were minority students; 61% took a part-time course load; 80% were employed; and 41% were employed full time. The diverse nature of students at the community college is also reflected in their stated reasons for enrolling. These reasons include a desire to better themselves financially, to obtain or improve job skills, to fulfill a personal interest, to earn a degree, or to prepare for transfer to a senior university (Chism & Banta, 2007; Conley, 2005; Grubb, 1999).

The diverse nature of community college students provides many challenges for community college faculty. Community college faculty members express frustration in working with underprepared students and dissatisfaction with the level of academic preparedness of their students (Blix, Cruise, Mitchell, & Blix, 1994; Bowen, Chingos, & McPherson, 2009; Burke, 2005; Chism & Banta, 2007; Grubb, 1999). Community college instructors in the mathematics division are frequently challenged by the prospect of working with students who are academically unprepared, and are therefore less likely to be successful than their counterparts attending four-year institutions. Because universities have restrictive admissions policies, the range of accepted students does not cover an overly large variety of skill sets, rather, it covers a smaller and more focused range. Despite their worthwhile mission to provide equitable educational opportunities to all students, community colleges are typically viewed as inferior to traditional colleges or universities. Oseguera and Rhee (2009) stated, “[There] is a nagging, pervasive sense, for both faculty and students, that being at a community college means being

near the bottom of the higher education totem pole” (p. 550). Community colleges, because they are primarily noted for their commitment to the lower-achieving student, are perceived as having watered down their curricula. Some university professors, according to a research study conducted by E. Barnett (2011), view community colleges as extensions of high schools with insufficient instruction by poorly trained faculty members. The principle of the open-door policy at community colleges is perceived to create an inevitable acceptance of “lower standards, which will eventually inundate the universities with transfers of poor quality” (Attewell, Lavin, Domina, & Levey, 2006, p. 897).

The third major source of difference is the faculty population and the conceptions of community college faculty. The differences between the conceptions of university faculty members and those of community college faculty members are very acute. In the research literature, these differences have been attributed to five primary factors. First, teaching is reported in the literature as being the existence of the community college professor (E. Barnett, 2011; Grubb, 1999) as opposed to doing research, which is the reason for the existence of the university professor. Second, community colleges are student-centered; therefore, faculty members are encouraged to be available to students at all times (Bahr, 2008). Third, given the broad range of abilities of students enrolled in community colleges, faculty members must have a correspondingly broad knowledge base of teaching in addition to their specialized disciplinary focus (Bailey, Crosta, & Jenkins, 2006). Fourth, the quality of teaching is the main criterion in the hiring process at community colleges (Barefoot et al., 2005). Finally, the community college is inclusive of all abilities and interests, providing educational opportunities to a diverse student population (Oseguera & Rhee, 2009).

Archibald and Feldman (2008) found that in community colleges there were many more faculty-student interactions and more active learning than in four-year institutions, especially at doctorate-granting universities. Kozeracki (2005) noted that one aspect of the community college that attracts applicants for a faculty position is the focus on teaching. Additionally, commitment to teaching is an important element of job satisfaction for community college faculty. The main difference between community college and university faculties is the perceived value of conducting research. In addition to teaching duties, university faculty members are also expected to conduct research; in a study of community college hiring practices, Bailey et al. (2006) found that one of the main reasons that some community college faculty members chose to work at the community college was its emphasis on teaching rather than research. A desire to avoid research-driven tenure processes at a university was cited in a study by Allen (2003) of new members of a community college faculty as another factor that drove participants to consider teaching at a community college.

These differences may be due in part to the fact that community college faculty members are typically required to possess a master's degree rather than a doctoral degree, despite the fact that both degrees demonstrate the possessor's mastery in a specific discipline. In 2005, according to the American Mathematical Association of Two-Year Colleges (AMATYC), the full-time faculty members who taught mathematics in two-year colleges had the following characteristics: female (44%), ethnic minorities (13%), above the age of 50 (46%), full-time faculty with a master's degree (82%), and full-time faculty with a doctorate (16%). Furthermore, there is a growing reliance on part-time faculty in community colleges; in 2005, adjunct faculty taught 44% of all two-year college mathematics sections (AMATYC, 2006).



A commonly held norm among higher education faculty members is a strong commitment to teaching. The findings from several research studies of faculty members at various higher education institutions, however, reveal that a huge difference exists among faculty members concerning the value of teaching as compared with other scholarly activities, such as research or presentations (R. Barnett, 1996). According to a study (J. M. Boyer, 1997) of undergraduate teaching at research institutions, teaching is generally undervalued. In Research 1 institutions, although teaching, research, and service are common workload components, there is a stronger emphasis on research. Fairweather (1996) revealed that department chairs routinely ranked “teaching quality” at the top of their lists of criteria for faculty promotion and tenure. At liberal arts institutions and community colleges, teaching quality was usually ranked first, whereas at research institutions it was more commonly ranked third. In practice, the promotion and tenure policies at research institutions were primarily based on research-related activities. Fairweather found that the faculty members within higher education research institutions in the study expressed that individual achievement in research and publishing were of the highest value rather than the act of teaching. One member went as far as to say that “in the end such evaluations of tenured professor performance revolve more around two questions: how [many] research publications have you done, and how much grant money have you brought in?” (p. 423).

This emphasis on conducting research hinders the diffusion of technology in classroom instruction at research institutions. If a technology is to be used, it must be perceived as being of benefit or value to the instructor, but promotion and tenure review boards seldom recognize instructional excellence or the development and implementation of instructional materials utilizing new technology as important (Camblin & Steger, 2000; Finley & Hartman, 2004; Lan,

2001). Technology integration is hindered in institutions that have merit, tenure, and promotion systems that support research over teaching, as faculty members are left with less time to advance their knowledge of technology, construct technology-rich curriculums, or implement new teaching strategies that are enhanced by the use of technology (Lederman & Niess, 2000; K. B. Smith, 2000). In a study by Frost and Teodorescu (2001), faculty members thought that the lack of incentives and rewards for using technology was directly linked to the lack of emphasis on teaching and the increased emphasis on research. Many faculty members believed that their time would be better spent pursuing the areas the university emphasized as necessary for tenure or promotion than on duties that were not valued as highly. Their general perception was that to achieve tenure, it would be wiser for a faculty member to concentrate on research and publishing, and not on using technology in teaching.

Until university promotion and tenure review processes recognize and value work with instructional technology in developing materials, there is little immediate benefit or value for faculty members seeking tenure or promotion. Because of barriers of intellectual property rights, faculty work requirements and compensation, Stone (1999) suggested that academic institutions adopt policies and incentives such as grants and recognition to address these issues. The incorporation of some or all of these rewards would help to create a culture that encourages technology integration. Stone explains that a faculty commitment toward the implementation of technology in instruction can only be obtained through a material demonstration of the value and benefits that it provides and by including it in the process of awarding promotion and tenure.

### **The Perceived Conflict between Research and Teaching**

The pressures of demonstrating sufficient research productivity are expressed by many faculty members, especially in research institutions at the doctorate-granting level. According to

several studies, teaching and service commitments are sacrificed in order to meet the demands of research (R. Barnett, 1996; Fairweather, 1996; Frost & Teodorescu, 2001; Johnston, 1997; Kline, 1977). Fairweather's (1996) study indicated a strong negative correlation between the time devoted to research compared to teaching in a study of 424 higher education institutions. He referred to the fact that "the more time faculty members spent on one activity, the less they spent on the other" (p. 365) as the "exchange" relationship, as faculty members' time is constantly divided by a competition between their teaching and research responsibilities. "As long as teaching and research are seen as competitors in terms of their status within universities, technology integration activities will remain in a tenuous position in the minds of faculty" (Johnston, 1997, p. 33). A better balance must be achieved in faculty reward systems in regards to the responsibilities of faculty members as instructors, such as teaching and service, and as researchers (Alsina, 2001; Fairweather, 1996). This balancing act often requires a new outlook on the roles of faculty members.

R. Barnett (1996) claims that accomplishments of researchers and teachers need to be as distinct and separate as their individual roles, and the priority of higher education institutions should be focused on the advancement of teaching and learning of the subject. All faculty members must remain up to date in the research community of their study, however "it does not follow that the teacher has to be engaged in actually moving the frontier" (p. 403). Barnett makes reference to a connection between the relationship of teaching and research and the relationship of a musician and the creation of music:

There is no demand on the soloist that he or she be a composer, be able to produce new scores. But, it is paramount that the soloist be so directly acquainted with the score that he or she is able to offer us a personal interpretation of it; in a sense, a critical commentary on it. Indeed, being a composer may even be a drawback; for it might lessen the critical distance that the soloist needs to maintain in order to bring a fresh interpretation to bear. (p. 403)

At many institutions, because the rewards of promotion and tenure are based in individual research accomplishments of faculty members and not their teaching milestones, research studies show that research and teaching are conflicting activities, although the university administrators claim that the two are mutually beneficial (Fairweather, 1996; Frost & Teodorescu, 2001; Johnston, 1997; Michalak & Friedrich, 1996; Weimer, 1997). In fact, at research institutions, the faculty members held in the highest regards have no teaching responsibilities at all (Knapper, 1997). Research studies show that teachers with lower basic salaries at research universities, doctorate-granting institutions and comprehensive colleges are the full-time faculty members that are more devoted to teaching and instruction (J. M. Boyer, 1997; Fairweather, 1996), while “faculty who spend the greatest time on research and scholarship receive the highest compensation, ...[and] the greater the publication record, the higher the compensation” (Fairweather, 1996, p. 367). The relationship between teaching and research may be more difficult and complex to dissect than previously thought, some researchers posit (Hilton, 1986; Johnston, 1997), as the institutional contexts may vary between facilities. More inclusive definitions of the constitution of research activities have been called on in reports from the Carnegie Foundation (J. M. Boyer, 1997), as well as developing and reshaping the concept of teaching. Conceptions of teaching must reach beyond just a collection of techniques, and must be viewed as an ongoing scholarly activity.

A greater emphasis on accomplishments in research activities is grounded in the fact that teaching accomplishments are difficult to measure (Hilton, 1978). Faculty members are generally reluctant to grasp the evaluations of their teaching, according to a study of support and the improvement of teaching among 240 of Emory University’s full-time faculty members (Frost & Teodorescu, 2001). The faculty members re-enforced the ideal that teaching could not be

accurately measured, and that these evaluations served more as a source of judgment rather than constructive criticism, and did little to guide or support their development as instructors. Many participants called for clarification of the role and expectations from instructors in departmental evaluations when considering promotion and tenure guidelines. The faculty members were supportive of evaluation from peers outside of the department, but expressed concerns involving the time required from development and review of undergraduate level teaching portfolios, as well as issues of validity and reliability of student evaluations. In the study, faculty members at Emory University expressed a desire for the administration to consider rewards of promotion and tenure with more emphasis on support for excellence in teaching.

### **What About the Mathematics Department's Culture?**

According to Bass (1997), “the disposition of many mathematicians toward the problems of education well reflects their professional culture” (p. 20). In general, most academic departments in a university have unique cultures that reflect their specific discipline. For example, the culture of the romance languages department will vary immensely from the culture of the mathematics department. As with other departments, the culture that exists within college and university mathematics departments is passed on through “the graduate school socialization process” (Braxton et al., 1996, p. 245). On the journey towards a mathematics Ph.D., candidates are most concerned with the courses, exams and other academic components of getting their degree, while their philosophies of the subject are internalized through their interactions with their professors and other graduate students (Braxton et al., 1996; Fairweather, 1996; Knapper, 1997). Because most members of the mathematics go through this form of training, their major focus is doing mathematical research rather than learning how to teach. In their instruction, they will most likely “try to reproduce the models that they have been exposed to during their own

education” (Keynes & Olson, 2001, p. 4) in an amalgamation of their individual experiences in their undergraduate and graduate programs, and as a result will not implement new teaching methods because of a lack of training specifically for teaching or professional development. As a career in teaching mathematics continues, the instructor’s “teaching pedagogy” is refined in the classroom through interactions with students and institutional expectations.

Mathematicians are motivated by a connection to the subject that allows them to see a certain beauty and elegance in mathematics (King, 1992), aspiring to contribute to the existing knowledge of mathematics through their own legacy or by creating a “lasting work of art” (Hersh, 1997, p. 86). Devoting most of their time to thinking about their research, they attempt to discover new ideas in their research through the use of rigorous proofs, and regard their work as real and timeless truths that are integral to the structure of the world. Many mathematicians hold themselves in high regard with a select few colleagues, and view mathematics as an esoteric subject in which a practitioner either has the aptitude for it or does not. The legendary mathematician Henri Poincaré (1910) observed:

We know that this feeling, this intuition of mathematical order, that makes us divine hidden harmonies and relations, cannot be possessed by everyone. Some will not have either this delicate feeling so difficult to define, or a strength of memory and attention beyond the ordinary, and they will be absolutely incapable of understanding higher mathematics. Such are the majority. (p. 322)

Even though academic mathematicians devote a considerable percentage of their time to classroom instruction, few mathematics departments provide them with professional preparation or development for mathematics pedagogy (Bass, 1997; Johnston, 1997; Weimer, 1997). A report produced by the National Research Council (NRC, 2003) on the evaluation and improvement of teaching mathematics at the undergraduate level disclosed that the existence of much needed formal and ongoing professional development in teaching for faculty continues to

be rare at most institutions. Although institutions have made access to technological tools for development of teaching methods, most faculty members have cited a lack of time to devote to them, and do not review research literature regarding teaching or learning (Weimer, 1997). Because they hold research as their highest priority due to promotions and rewards (Johnston, 1997), many faculty members do invest time for developing their pedagogy or teaching methods. Krantz (2000) succinctly stated,

Depending on the sort of department in which he [the mathematician] works, he may also feel that hotshot researchers and book writers get all the perks and that “mere teachers” are viewed as drones. After all, he/she has tenure and is probably more worried about where his/her next theorem or next grant or next raise is coming from than about such prosaic matters as calculus. (p. 7)

### **Computing Technology and Undergraduate Mathematics Education**

Computing technology has come to be seen as providing potentially valuable tools for mathematics education reforms, not only at the elementary and secondary levels, but for higher education as well. Computing technology is important in undergraduate mathematics education because of its impact and influence on mathematical research, mathematical thinking, and mathematics teaching and learning. As a result, higher education mathematics faculties have been given greater access to innovative technology. Although federal, state, and local governments and organizations (e.g., Mathematical Association of America, 1991) recognize the importance of computing technology in mathematics education and mandate policies specifying their use on all levels, their usage in undergraduate mathematics teaching is far from universal and even further from optimal (Benjamin, 2000). Despite better access over the years, mathematics faculty members’ utilization of computing technology has remained low. Although some have started using computing technology to teach in innovative and creative ways, most

mathematics professors at higher education institutions make little use of computing technology as a tool for teaching (Biggs, 1999; Lim, 2000).

### **Computing Technology and Mathematics**

Some educational researchers and mathematicians have identified computing technology as the impetus of change in mathematics and have claimed it has changed what mathematics is and what methods are used in mathematical research (Norton, McRobbie, & Cooper, 2000; LaBerge et al., 1997; Steen, 1987). The nature of mathematics has changed considerably due to the addition of computing technology. Not only does this technology amplify computing, it also transforms magnitude and dimensions of mathematical research (Penn & Bailey, 1991). According to the NRC (1991), computing technology has had a major impact on modern mathematical research:

Computers have profoundly influenced the mathematical sciences themselves, not only in facilitating mathematical research, but also in unearthing challenging new mathematical questions. (p. 16)

In recent years, the utilization of computing technology as an active tool for mathematical research has become increasingly more prevalent, and new mathematical theorems and conjectures have been discovered partly or entirely using it. Furthermore, it has centralized access to updated research publications, and mathematics has become a much more collaborative discipline through email communication (Pierson, 2011). A common misconception is that computing technology is useful only to applied mathematical fields such as combinatorics, algebraic geometry, differential equations, dynamical systems, differential geometry, algebraic topology, probability and statistics, numerical analysis, computer science, fluid mechanics, and mathematics education. However, computing technology has recently had a major impact on theoretical mathematics as well (Pierson, 2011). Although contributions are naturally larger to



the applied mathematical fields where numerical approximations are routine, computing technology is being used to provide tools to make advances in pure fields such as number theory, group theory, and graph theory.

Computing technology is capable of generating data and demonstrating it visually through a variety of representational options. Use of computing technology in mathematics primarily provides new insight and intuition. Technology can help to discover new mathematical patterns and relationships, and then uses displays to demonstrate the underlying principles. With technology, a mathematician can test conjectures, experiment results towards formal proofs, and confirm the results derived from them. The technology can also recognize any symbol or combination of symbols; thus, it can be used to discover proofs in mathematics, to generate new combinations, and to employ means-ends analysis in general problem solving.

According to Heid (2002) and Grassl and Mingus, (2007), computing technology has changed the very nature of mathematical experience. They suggest that mathematics, like physics and chemistry, may yet become an empirical discipline, a place where new concepts are discovered because they are seen. According to Keith Devlin, a well-known contemporary mathematician who writes a column on computing technology for the *Notices of the American Mathematical Society*, computing technology is changing the nature of proof in mathematics. He posits that in the near future the importance of proof will diminish, saying, “You will see many more people doing mathematics without necessarily doing proofs” (quoted in Horgan, 2003, p. 652). Currently, computing technology is commonly being used to provide aid in proving mathematical theorems. The classical example that began the trend of using computing technology for doing proofs in mathematics occurred in 1976, when Kenneth Appel and Wolfgang Haken used a computer to check a large, but finite, number of cases that could not be

ruled out by humans. The resulting data, made possible by the new technology, transformed the Four-Color conjecture into the Four-Color theorem. This theorem was the first major theorem to be proved using a computer, and it opened the door to new possibilities for future research.

### **Computing Technology and Mathematics Faculty**

In a recent quantitative research study of 596 mathematics faculty members by Quinlan (2007), participants were asked about their usage of computing technology, including all types of software (email, Word Perfect, Excel, mathematics software, etc.). More than half of the respondents (54.3%) said they used software daily for email communication purposes, and more than three quarters (79.9%) did so at least weekly. The study also revealed large percentages for daily usage in teaching and in presenting results, gaining insight, performing computational reasoning and calculation, and doing visual representation and reasoning. A majority of the mathematics professors indicated, however, that they did not use computing technology for proof checking, detecting differences or similarities, creating new representations, performing logical induction or deduction, making predictions, or verifying analytical results.

The participants in Quinlan's (2007) study also indicated the importance of using computing technology in the following courses: Number Theory, Discrete Mathematics, Linear Algebra, and Calculus (36%, 51%, 53%, and 45%, respectively). The majority of participants said they believed the future advancements in computing technology would have a direct impact on their mathematical work, primarily through an increase in the speed of computing technology's central processing unit (CPU). The enhanced speed would facilitate the use of multiprocessors, provide greater access to digital libraries, allow more online availability of

literature (e.g., electronic journals), and aid in software development for topics such as abstract algebra.

The same study showed that a considerable amount of time is spent working with computing technology. More than one quarter (25.6%) of the participants reported interacting with computing technology for more than 30 hours a week, and almost 60% spent more than 20 hours a week using computing technology in some capacity. Overall, the participants in this survey ranked themselves high on a scale of computing technology expertise. Approximately 40% of the participants selected 8 or above on a 10-point scale when asked to indicate their level of expertise with computing technology, whereas only 20% rated themselves below a 5. When examining self-ranking technological expertise, Quinlan (2007) found nearly identical distributions across university professorial ranks, which suggests that the younger mathematicians do not see themselves as more technologically savvy than the older mathematicians. This conclusion, however, might just as easily be interpreted as the older generation of mathematicians only perceiving itself to be as technologically savvy as the newer generation.

In Quinlan's (2007) study, the majority of participants (78%) indicated that technology was significantly important to the field of mathematics. Only 30%, however, believed technology was important in primary or secondary school mathematics. Additionally, 62% of the participants indicated that technology was highly important to their specific area of research. Only 7.5% responded that technology had little to no importance to mathematics, but 22% indicated technology had very little or no importance to their area of research. The participants also expressed the view that technology is more important in teaching mathematics (59%) than in learning mathematics (49%). Slightly more than 5% indicated that technology was not at all

important to learning mathematics, even in graduate school. Regarding the integration of computing technology, approximately 50% thought it is important in undergraduate mathematics education, and 59% had similar beliefs with regard to graduate school mathematics. The participants indicated that the importance of technology increases with grade level. Overall, the participants expressed negative attitudes toward students' use of technology, especially calculators, in elementary school.

### **Computing Technology for Teaching and Learning in Undergraduate Mathematics**

In addition to being a central tool in mathematical application and research, computing technology has also provided tools for both teaching and learning mathematics. Computing technology affects mathematical thinking and understanding, content and curriculum, and teaching and learning (Heid, 2002; Judson, 2007; Kaput, Noss, & Hoyles, 2002). Computing technology has not only changed *how* mathematics is taught, but has also redefined the idea of what type of mathematics *should* be taught. Over the past three decades, many forms of computing technology have been introduced into the undergraduate mathematics classroom, and these have had a substantial effect on the way mathematics is taught and learned (Higgins & Moseley, 2001; Zbiek, 1995). Various forms of computing technology, such as calculators, computer algebra systems, and interactive Web sites, have become important elements in undergraduate mathematics curricula. Besides becoming more prevalent in the classroom, they have been major tools used to initiate educational reforms at the undergraduate level. In fact, some researchers claim that undergraduate mathematics reform initiatives have no chance to succeed without technology. A prominent undergraduate mathematics education researcher, Heid (1998), claims that “the single most important catalyst for today’s mathematics education reform

movement is the continuing exponential growth in personal access to powerful computing technology” (p. 5).

Several researchers suggest that the use of technology will enhance conceptual learning and that successful education projects will integrate technology into the curriculum (e.g., Higgins & Moseley, 2001). In a report released in 1991, the Mathematical Association of America (MAA) stated that technology is essential in undergraduate mathematics, and it recommended that collegiate mathematics faculty members incorporate computing technology naturally and routinely into their teaching. The MAA called for technology to be used to enhance the understanding of mathematical ideas and recommended that computing technology be included in the entire undergraduate major program. That same year, the NRC (1991) echoed the MAA position concerning undergraduate mathematics teaching:

Nothing in recent times has had as great an impact on mathematics as computers, yet in most college courses mathematics is still taught just as it was 30 years ago as a cerebral, paper-and-pencil discipline for which computers either are irrelevant or can be ignored. Computers serve mathematics these days as indispensable aids in research and application. Yet only in isolated experimental courses has the impact of computing on the practice of mathematics penetrated the undergraduate curriculum. (p. 17)

Computing technology can be used to facilitate mathematical discovery and to assist students in learning and making connections among concepts. Several researchers identified technology as a tool that supports mathematical thinking because technology makes highly abstract, sophisticated, and fundamental mathematical ideas accessible to students (Dubinsky & Schwingendorf, 1991; Heid, 2002). Computing technology provides visual representations of abstract mathematical objects, and visual exploration and reasoning is an essential analytic tool to mathematicians (Penn & Bailey, 1991). Furthermore, computing technology can also provide concrete data in a number of ways; with these data, students can more easily discuss and search for patterns and analyze the elements of a problem (Heid, 1988).

Over the past three decades, researchers have completed an abundance of studies that examine the use of computing technology in undergraduate mathematics classrooms (Drijvers, 2000; Heid, 1988; Stacey et al., 2002). Computing technology has proven beneficial, with many studies demonstrating that a student's conceptual understanding of mathematics will rise as a result of technology utilization (Stacey et al., 2002; Wepner, Scott, & Haysbert, 2003). Furthermore, educational efforts have produced extensive research focused on the effects of computing technology on student achievement (Dunleavy & Heinecke, 2007), attitude (Heid, 2002), engagement and creativity (Drijvers, 2000), conceptual development (Artigue, 2001), multiple representations (Dunleavy & Heinecke, 2007), and understanding (Heid, 2002).

Studies have also demonstrated that this technology can be used to remove the burden of mastering computational skills, which then provides more time for students to explore mathematical concepts in class (Dunleavy & Heinecke, 2007; Heid, 1988). The use of computing technology can also save instructional time because the classroom time that an instructor would normally have spent performing routine hand calculations and graphing can instead be spent on interpreting results of real-world problems and mastering concepts (Artigue, 2001). In addition, computing technology can provide students with poor or borderline mathematics skills the opportunity to study levels of mathematics they would never have understood otherwise. The technology can provide alternate ways of seeing a problem, and can be used to generate a larger number and a greater range of examples for students to encounter (Heid, 2002). With computing technology, the existing curriculum can be extended by increasing the range of problems with which students come into contact. Computing technology provides students with richer mathematical experiences because it allows the student to handle mathematical questions more

complicated than most could do with only pencil and paper (Kersaint, Horton, Stohl, & Garofalo, 2003).

In some research studies, there have been reports of negative learning outcomes. For example, Doerr and Zangor (2000) found that students often use technology without having a meaningful strategy. They documented that students may attack a problem by just pressing buttons without a true understanding of each option's use. These research findings were supported in Forster and Taylor's (2006) study; they found that some students, when first introduced to the graphing calculator, concentrated on pressing the correct buttons and did not think about understanding what mathematical operations were being used. Stacey et al. (2002) demonstrated that some students significantly lacked in areas of algebraic insight. The students had difficulty in recognition of the pen-and-paper expressions when compared to the computations of the technological device. Some researches suggested that correct syntax within the technology is necessary and a lack thereof can create this problem. The successful use of computing technology requires compliance with strict syntax rules; failure to follow those rules will result in an incorrect result or expression. Because students sometimes have problems remembering and understanding the correct syntax to use when entering data and algebraic expressions, they are not always able to recognize equivalent algebraic processes. In a study by Graham and Thomas (2000), when the computing technology produced results in inconsistent forms, the students became confused and spent valuable time investigating the various forms rather than producing a mathematical result. Graham and Thomas suggested that students must possess a level of algebraic insight in addition to a working knowledge of the machine-specific alternative syntax that will enable them to recognize when multiple mathematical expressions are the same.

It is evident that the effective use of computing technology in the mathematics classroom can be quite beneficial; however, the simple presence of computing technology does not and will not automatically produce positive results. The faculty must know how to integrate the technology efficiently into the learning process in order to produce successful learning outcomes. Frequently cited problems of incorporating computing technology into mathematics classrooms and curriculum include the shortage of many elements: knowledge, time, software, hardware, and confidence in the product. Many faculty members already feel pressed for time between teaching and research responsibilities, so it is difficult to convince them to make time to learn about new technology. Many educational institutions are focused on cost-cutting measures; they are not going to be inclined to spend money on new technology that is perceived with some skepticism by the faculty members. In addition, the use of this new technology can require upgrading the hardware found in classrooms, which further increases the cost of integrating technology into the curriculum (Harley, 2001). In Quinlan's (2007) study, 556 mathematics faculty members were interviewed to determine their beliefs and perceptions about computing technology and its usefulness in the classroom. Of these participants, 21% said technology in the classroom was not necessary; 15% indicated that their own lack of expertise limited their use; and 18% cited a lack of time to learn the software. Only 7% of the participants reported that no factor limited their use of technology.

The perceptions and knowledge regarding computing technology of a mathematics instructor heavily influences the activities that he or she creates and implements to teach students mathematics (Hamrick, Schuh, & Shelley, 2004). Although common sense tells us that a teacher's attitude toward technology will affect the ways in which the technology is used, there is "precious little evidence about [the faculty member's] attitudes and conceptions about



technology and how the university mathematics community as a whole feels about this issue” (Alsina, 2001, p. 406). Doerr and Zangor (2000), in their effort to study instructors’ experiences with technology in the mathematics classroom, stated that for instructors to effectively teach with technology, they must believe in its value, be confident in its use, and be aware of the extent of its abilities.

Hamrick, Schuh, and Shelley (2004) suggested a four-step integration process for instructors to follow. This process is designed to help faculty members become more skilled and effective when using technology in the classroom, while also helping to “mold their understandings, conceptions, and perceptions” (p. 420) of teaching with technology. Zbiek and Hollebrands (2008) suggest that the instructor begin by simply playing with the technology, becoming familiar with its capabilities. Once instructors have become comfortable with navigating the software, they should then focus on using it in a structured way as an instrument for doing mathematics. During the play stage, it is recommended that the instructors rely on appropriate guidance such as teaching materials and tutoring. The development experienced by the instructor during this stage “includes the transition of the technology as the developer’s tool into the teacher’s instrument for doing mathematics” (p. 295). The instructor is encouraged to interact with students and other colleagues rather than just the classroom activities that recommend technology. The instructor will build confidence in his or her abilities with the technology through these interactions and collaborations. Next, technology should be integrated into classroom instruction, even if only gradually, or possibly only with groups of students more advanced in the subject. Finally, the instructor should assess what the new technology is actually teaching the students by asking for student feedback, or by comparing test scores with students in other classes. By following this program, instructors should find that the technology is more

accessible than their preconceived notions would suggest, and it will assist them in successfully integrating the technology in a constructive way.

### CHAPTER 3: METHODOLOGY

I have no data yet. It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts.  
Sir Arthur Conan Doyle (quoted in Creswell, 2003, p. 22)

Mathematics education experts are asking for clearly articulated a priori theoretical frameworks to provide a structure for conceptualizing and designing research studies. The emphasis on an a priori theoretical framework development reflects the view that a research study well-anchored in theory will contribute more to mathematics education practice than an atheoretical one. What is a theoretical framework? According to Creswell (2003), it is the abstraction of general ideas from particular experiences that serves as the basis for a phenomenon that is to be investigated, representing its relevant features as determined by the research perspective, and serving as a magnifying glass to conceptualize and guide the research.

One of the most perplexing problems for a novice researcher is the development of an adequate theoretical framework for a proposed study. The process requires asking the following initial questions before implementing the study: What methods will be used? What research methodology will govern the choice and use of methods? What theoretical perspective lies behind the methodology? According to Creswell (2003), a theoretical framework should include four dimensions, each of which informs the rest: epistemology→ theoretical perspective→ research methodology→ methods. In this study, I adopted symbolic interactionism (Merriam, 1998) as the epistemological stance, and the data were analyzed to generate a grounded theory (Glaser & Strauss, 1967; Strauss & Corbin, 1998). More specifically, the theoretical framework

for this study can be expressed as follows: symbolic interactionism→ phenomenology  
→grounded theory→ initial questionnaire, nonparticipant observations, interviews, classroom artifacts, and online communications.

Before delineating the context underlying this study and outlining the research methods and principles used, I want to refer back to my starting point: the research question. To reiterate, the purpose of this study was to examine calculus instructors' conceptions of teaching calculus with or without computing technology. I have adopted the term *conception* to avoid the ambiguities associated with the terms *belief*, *perception*, *norm*, *attitude*, and *value* used in several research reports (Nespor, 1987; Pajares, 1992). In the literature, these terms, especially the term *belief*, have been subject to a variety of interpretations. Despite acknowledging the need for explicit definitions to distinguish or separate one effective educational outcome from another (Pepin, 1999; Thompson, 1992), mathematics educators use theoretical definitions of *belief*, *knowledge*, and *attitude* inconsistently, and most research studies on these effective educational outcomes avoid giving an explicit definition and settle for an operational definition. Aside from not being explicit about meaning, many researchers use these terms interchangeably, and even when a definition is given, the researcher may not be satisfied with it (Pehkonen & Törner, 2004).

In the present study, by the term *conception*, I refer to a personal assessment of one's knowledge, principles, beliefs, values, and concepts that guide teaching activity. It has been given many names: *perspective*, *knowledge base*, *personal philosophy*, *value*, and *belief* (see, e.g., Calderhead, 1996; Carter & Doyle, 1987; Pehkonen & Törner, 2004). I assumed that instructors' conceptions are not fixed or inherent in their educational practices. I also assumed

that conceptions play a major role in establishing a sense of personal and social identity for instructors through their experiences.

An examination of conceptions regarding the practice of using computing technology suggests particular methods that are aligned with naturalistic inquiry. Symbolic interactionism provides an approach for the analysis of human activities that focuses on how people interpret and define situations influencing social action (Merriam, 1998). Symbolic interactionism is based on the study of social processes and how people understand the world through meaning that is created and changed continuously by self-reflection and social interactions with others; meaning is assumed to be interactional and interpretive. This theoretical framework stems from the idea that “people transform themselves and their worlds as they engage in social dialogue” (Strauss & Corbin, 1998, p. v). Symbolic interactionism specifically emphasizes three fundamental premises of how people create meaning together within a particular context (Merriam, 1998; Strauss, 1987). First, people act towards something according to the meaning that it has for them. Meaning is always dynamic and purposeful, and it cannot be separated from the interpretation of behavior. Second, people constantly change their personal interpretations of something once they communicate with others and consider the actions of others toward it. Third, meaning is constantly changed in interpretive processes as people engage with the world.

I used a grounded theory approach as a methodology to explore and then understand and generate descriptions of instructors’ conceptions about using or not using computing technology in teaching and learning calculus. This approach also helped me to achieve methodological cohesion—when the research question fits the method of data collection, method of data analysis, participant selection, assumptions of the approach, and results expected from the approach. In implementing grounded theory, my aim was to discover, understand, and present a

rich description of the meaning of using (or not using) computing technology from the instructor's perspective (Bogdan & Biklen, 2002). In addition, I also wanted to discover what relationships exist between an instructor's conceptions of teaching calculus with (or without) computing technology and his or her conceptions of teaching and learning calculus.

Grounded theory is an inductive research method that generates theory from data that are gathered, organized, and examined systematically in an ongoing interplay between analysis and data collection (Glaser & Strauss, 1967; Strauss, 1987). Grounded theory, therefore, fits this study well because, as a methodology, grounded theory assumes individuals in groups comprehend events from a personal perspective, and common patterns of behavior can be discovered. Grounded theory captures the complexities of the context in which the action unfolds (Glaser, 1998). One of the strengths of grounded theory is that it explains what is happening in real life rather than describing what should be going on. As Glaser (1992) argues, the purpose of grounded theory is not to discover *the* theory but rather a theory that aids understanding in the area under investigation. He also recommends that the researcher enter the field "with abstract wonderment of what is going on that is at issue and how it is handled" (p. 22). The researcher's purpose in using the grounded theory method is to provide a tentative explanation of a social process or construction by identifying the core and subsidiary processes operating in it (Glaser, 1992; Strauss & Corbin, 1998).

The main advantage of using grounded theory is that concepts do not have to be identified as predetermined variables but emerge from observations and discussions with participants. The goal, therefore, is to develop an "integrated set of hypotheses [that accounts] for much of the behavior seen in a substantive area" (Glaser, 1998, p. 3). The researcher asks: What are the concerns of people in the substantive area, and what accounts for most of the

variation? In grounded theory, the researcher looks for the principal theme or themes that integrate behavioral patterns explaining the main concern for the people in the setting. The researcher classifies plausible relationships among concepts through a systematic, detailed examination of data; the aim is to bring out the complexity of what lies in, behind, and beyond the data (Glaser, 1998). Glaser and Strauss (1967), developers of grounded theory, also suggest using the theory to explore for situations in which a change process or transition is expected or ongoing and has a number of stages. A cursory glance over current practices of teaching calculus will reveal that conceptions about using computing technology in learning and teaching calculus can be represented along a continuum of views (Almeida, 2000). A grounded theory approach mainly seeks to explore and understand processes of transition, change, and the evolution of social constructions in areas previously unexplored or underexplored. The use of this approach to develop an understanding of calculus instructors' conceptions regarding the use of computing technology in teaching and learning calculus provided methodological cohesion for this study.

### **Institutions and Participant Selection**

The study was conducted in the mathematics departments of a large public research university and a large community college, both located in the southeastern United States. The site selection was based on previous research demonstrating how the institutional culture in higher education is shaped by the mission of the institutions (Beard & Hartley, 1987; Bogdan & Biklen, 2002; Burke, 2005; Cox, 2001). By employing two educational settings, I was able to explore and compare the cultures of two mathematics departments, where ideologies, norms, and values are internalized through a socialization process (Braxton et al., 1996, Fairweather, 1996; Knapper, 1997). In addition, working with two institutions and selecting a broad range of

information-rich participants enabled me to address the aims of the study, as well as draw meaningful conclusions from the results.

As a part of an initial participant selection strategy, I generated a list of all the full-time mathematicians from the university and a list of all the full-time mathematics instructors from the college. All department members on each list were asked to complete a voluntary initial questionnaire that focused on using computing technology in teaching calculus (see Appendix A on page 184). The questions were a combination of multiple-choice, Likert-scale, and open-ended items. The goal of the questions was to obtain initial information about the instructors' familiarity with the calculus reform movement, their comfort level with using computing technology, and their perception of the role of computing technology in the classroom. I used these data only to select participants and design interview questions.

To better understand the content, character, and expression of calculus instructors' conceptions of using or not using computing technology in teaching and learning calculus, I chose a set of three calculus instructors from each institution for the present study. The selection of the participants was purposeful and was partly based on their initial questionnaire responses. Because the study aimed to explore a complex and little-understood phenomenon, the participants were chosen because of their experience with the phenomenon being studied, as well as their ability to articulate the meaning of that experience. Furthermore, a selection of information-rich participants from broad backgrounds also aimed to facilitate the expansion of the developing theory (Bogdan & Biklen, 2002; Glaser, 1998). Among the three participants from each institution, I included one instructor who was using computing technology in calculus classes during the study, one who had never attempted to use computing technology, and one who had used computing technology in the past but was not using it currently. By selecting such



individuals, I aimed to discover similarities as well as differences in experience among the participants. The six calculus instructors were chosen because they were similar in some respects and dissimilar in others. All the names of participants and institutions used in this dissertation are pseudonyms to protect their privacy.

**Braun University.** The first institution used for this research was Braun University, a prominent Research I university, located in a small city in the southeastern United States. The full-time and part-time faculty members numbered over 1300, and the student body exceeded 34,000—including in-state, out-of-state, and international students. The university was highly selective, and students were admitted based on various criteria, including SAT or ACT examination scores. According to its Web page, this institution accepted students from various racial, ethnic, religious, and economic backgrounds who demonstrated excellent academic promise and personal integrity. The faculty handbook emphasized the pursuit of excellent teaching, productive research agendas, and the creation of scholarly work.

At Braun University, the mathematics department faculty consisted of 35 full-time mathematicians. Mathematics instructors generally taught in the department's classrooms but might regularly use classrooms outside the department building as well. In this study, all classroom observations were made in mathematics department classrooms, each of which had three chalkboards and computer projector equipment. The department also had several computer labs that were accessible to students. The department offered a wide range of graduate and undergraduate mathematics courses, as well as mathematics content courses for education majors. The department granted bachelor's, master's, and doctoral degrees in mathematics. In any given semester, the department offered various sections of Differential Calculus classes for different clientele, such as Calculus for Economics for economics majors, Calculus I Science &

Engineering for engineering majors, and Differential Calculus Theory for mathematics majors. At Braun University, the student population for the calculus courses reflected typical demographics for freshman-level courses at other universities: recent high school graduates in the 18- to 20-year-old age bracket. Class sizes numbered 30 to 36 students for calculus classes, and most students took calculus in their first or second term.

The majority of students took the generic section of calculus: Analytic Geometry and Calculus. In the fall semester of 2008, when data collection for this study started, the department offered 26 sections of Analytic Geometry and Calculus, 2 sections of Calculus for Economics, 6 sections of Calculus I for Science and Engineering, and 1 section of the Differential Calculus Theory course. Prior to Fall 2008, the Analytic Geometry and Calculus course was a 4 credit hour course, with 3 hours of in-class lecture on calculus concepts and 1 hour of independent computer laboratory work to show the applications of calculus ideas and concepts. In most cases, the classes and computer laboratory sections were taught by different instructors. In Fall 2008, the department replaced the computer laboratory section of the course with a 1-hour problem-solving section conducted by teaching assistants. The format of the course was a 50-minute meeting three days a week or 75-minute meetings two days (lecture format) a week with an additional 50-minute problem-solving period one day a week. According to several faculty members, the decision to take this retrograde step away from the use of computing technology in the Analytic Geometry and Calculus course was supported by the majority of the faculty. According to departmental policy for the course, calculus instructors were expected to cover required concepts in their classes but were free to adjust the syllabi or use any kind of computing technology as they saw fit. I contacted 10 Braun University calculus instructors before selecting the 3 (2 male and 1 female) to participate in the study. A brief profile of each participant follows.

**Joe.** Joe had earned a Ph.D. in mathematics and, at the time of the study, was a professor of mathematics at Braun University. He taught introductory calculus classes regularly. I had been a student of his in a previous graduate level mathematics course and had some idea of his conceptions of teaching calculus using computing technology. Joe had more than 28 years of experience teaching college-level mathematics and had received awards for his teaching. As a mathematician, Joe had almost 20 years of experience in using graphing calculators in the classroom in innovative ways. He was generally considered by his students and his peers to be an excellent mathematics instructor. At the time of the study, Joe was teaching a Calculus I course with approximately 32 students enrolled in the class.

*Joe:* Technology is a big part of the students' lives, and the more you understand where the students are coming from, the better it is—the easier it is to teach them, to relate to them. (Interview, September 5, 2008)

**Lynn.** Lynn was a European female who had earned a Ph.D. in mathematics in the United States, and, at the time of the study, had been a professor of mathematics at Braun University for 15 years. She had 20 years of experience teaching college-level mathematics. She believed her teaching style came from her own mathematical experience; she focused more on doing mathematical proofs and providing reasons behind concepts than on the applications of calculus concepts. I selected Lynn for three reasons: She had been recommended by other mathematics professors; she was known for not using computing technology at all in her calculus teaching; and she was interested in my research and willing to participate. At the time of this study, she was teaching a Calculus I course with approximately 29 students enrolled.

*Lynn:* I have a fairly strong bias against it [technology]. I have a reason for that bias. I deal with a lot of students; I have dealt with a lot of students for a long time, and the one thing I see students consistently do is turn off the brain when they turn on the calculator. (Interview, September 6, 2008)

**Ken.** Ken had earned a Ph.D. in mathematics and had been teaching at Braun University for 3 years. He had 8 years of experience teaching college-level mathematics and received a teaching award from his previous institution. For the previous 4 years, Ken had used instructional technology in his courses, as well as in his research. I selected Ken for two reasons: As a relatively new faculty member, Ken seemed to find it somewhat easier to adapt to new instructional technology; and, in a previous private conversation we had made, Ken told me that he used computing technology in his calculus classes in the past. But he was against the use computing technology in teaching calculus, and I wanted to understand his conceptions of using computing technology beyond what I had heard. At the time of this study, he was teaching Calculus I with approximately 31 students in the course.

*Ken:* I have mixed feelings about the graphing calculator, the TI89, and so on. I sometimes let them [the students] use it. (Interview, September 8, 2008)

**Fairway College,** The second institution involved in this study was Fairway College, a public community college established in the early 1960s and also located in the southeastern United States. The full-time and part-time faculty members numbered over 300; approximately 7500 enrolled students attended classes on two campuses (the student population had an almost equal gender distribution, with less than 20% minorities, including African American, Hispanic, and Native American). According to its Web page, the college's mission was to provide a bridge between high school and baccalaureate studies as well as open access to education beyond secondary school, including but not limited to vocational and technical preparation and remedial education. The college faculty handbook emphasized the comprehensive components of teaching and public service for faculty members. The college granted a wide range of associate degrees along with bachelor's degrees in seven fields. Students mostly came from surrounding counties, and most of them were the first in their families to attend college. The college had an open

admission policy; therefore, students varied with respect to their personal and academic backgrounds as well as their educational goals and personal aspirations. In recent years, the college had been trying to use classroom and laboratory space to better accommodate a growing student population without investing in additional facilities. The administration had provided several incentives for the faculty to motivate them to teach online or hybrid courses—courses that included elements of both traditional face-to-face and online course components.

At Fairway College, the mathematics department consisted of 26 full-time instructors and offered several mathematics courses, including learning support classes; classes in statistics, calculus, linear algebra, and differential equations; and mathematics content courses for elementary education majors. Mathematics courses at Fairway College were taught in the department's own classrooms, which varied in size but were well equipped, with whiteboards, overhead projectors, and smart board equipment in each room. In the Fall 2008 semester, when data collection for this study began, the department was offering 7 sections of Differential Calculus and 2 sections of Calculus for Business. At Fairway College, the student population demographic for calculus courses included a large number of recent high school graduates in the 18- to 20-year-old age bracket and a small number of nontraditional students (over 24 years old). Calculus class sizes at Fairway College were normally about 26 to 32, and most students took calculus in their second or third term. Calculus classes usually met for 110 minutes in lecture-format blocks two days a week. According to departmental policy, calculus instructors were expected to cover required concepts in their classes but were free to adjust the syllabi or use any kind of computing technology except the TI-89 graphing calculator (or any other calculator that had Computer Algebra System capability) as they saw fit. I contacted 7 calculus instructors

before selecting the 3 participants (two females and one male) from Fairway College to participate in the study. A brief profile of each participant follows.

***Dorothy.*** Dorothy had earned a Ph.D. in mathematics and, at the time of this study, was a professor of mathematics at Fairway College. Her research interests included differential geometry and topology. Before entering a doctoral program in pure mathematics, she spent 1 year in a mathematics education doctoral program. She had more than 20 years of experience teaching college-level mathematics. Dorothy was passionate about incorporating technology (graphing calculators and Maple—a commercial software package) into her mathematics teaching, and she was involved in several different distance education programs. At the time of this study, Dorothy was teaching a Calculus I course with approximately 30 students in the class.

*Dorothy:* Once you get started doing calculus with technology, you get so used to computing derivatives integrals using Maple, it is so hard to go back to doing it by hand. (Interview, September 14, 2008)

***Ron.*** Ron was in his 30th year of teaching when the data collection began. He had both a B.S. and an M.S. in mathematics and had completed additional graduate coursework to obtain a teaching certificate in the early 1980s. He had received a number of teaching awards and had been involved in some curriculum development projects at Fairway College. At the time of the study, Ron was an associate professor of mathematics. He had never attempted to use computing technology in his calculus teaching. He remained critical and held strong views on the appropriate and relevant use of technology. At the time of this study, Ron was teaching a Calculus I course with approximately 28 students in the class.

*Ron:* It makes me think technology is bad, because I don't know how to use it very much. I don't let them use calculators. So many times, I have seen students who will do many steps and very complicated things within the calculator that could actually be done faster by hand. (Interview, September 18, 2008)

**Janet.** Janet earned a M.Ed. in mathematics education, and her undergraduate degree was in business. She was an assistant professor of mathematics at Fairway College at the time of the study. She had taught 2 years at a high school prior to teaching at Fairway and had 6 years of experience teaching college-level mathematics. At the time of this study, Janet was teaching a Calculus I course with approximately 30 students enrolled. I selected Janet because she was using computing technology in the course, but she was against letting her students use it in class. Janet perceived the main advantage of computing technology as a means of providing prompt feedback to student responses and viewed technology as a tool for improved communication between student and instructor. However, as a result of her past experiences, Janet was opposed to the use of computing technology in teaching calculus.

*Janet:* I have some negative experiences with technology. So my experience is that there are students who have used calculators so extensively that they don't even understand basic arithmetic from grammar school. The idea is "There is this black box, and it will give me the answer" as opposed to "Okay, I can figure this out for myself." (Interview, September 14, 2008)

## **Data Collection**

Understanding conceptions is very problematic because personal decisions and comments result from different causes. There are strong connections between an instructor's conception of using or not using computing technology in calculus classes and other conceptions that he or she might have about such matters as the nature of mathematics and mathematics teaching and learning. Furthermore, in mathematics classes, the impact of an instructor's conceptions of his or her teaching typically occurs implicitly rather than explicitly (Pepin, 1999). To study instructors' conceptions, an examination of their words alone is not enough—the examination should be supplemented with classroom observations and other data sources (Pajares, 1992; Thompson, 1992).

In this study, the main sources of data were questionnaire responses, recorded interviews, field observation notes, and artifacts (e.g., calculus project handouts, instructors' curriculum vitae, examinations, and instructors' online communication postings). Each research participant was asked to participate in three semi-structured interviews that took the form of a conversation intended to address the research questions (Creswell, 2003). The semi-structured interviews aimed to facilitate a participant-led discussion that freed me to gather information by supplementing participant reflections through questions that probed for clarification and further explanation. Each participant was interviewed three times over the course of the academic semester to gather information about his or her conceptions of using computing technology in teaching and learning calculus. The end result was a total of 18 interviews from which the data were gathered. Interviews 1 and 2 ranged from 45 to 85 minutes per participant. The goal of the first two questions in the first interview was to give the participant an opportunity to discuss his or her personal conceptions of mathematics, technology, and the benefits and drawbacks of teaching and learning calculus with computing technology. The participants were asked questions regarding their previous experience in teaching calculus with computing technology, as well as what they perceived to be the ideal way to incorporate computing technology into the classroom. A complete list of the main questions across all three interviews is included in Appendix B on page 187.

As a researcher, my primary goal was to motivate the participants to discuss their teaching methods and their conceptions about teaching and learning calculus with computing technology. The format of the interviews was designed to encourage a free-flowing dialogue, with opportunities to explore many channels of interests. The third interview specifically focused on any lingering issues or questions that I felt required clarification. Interview 3, therefore, was



brief and did not generally exceed 30 minutes. The overall purpose of the first two interviews was to uncover information about how each participant thought of and valued mathematics, teaching calculus in particular, their perspective on the learning process undertaken by their students, and the use of computing technology in the classroom. Therefore, after the first two interviews with each research participant, I tried to seek new insights by reflecting on the data and the interview process.

In addition to interviewing the participants, I observed each of them teaching a calculus lesson on at least five occasions, during which I took extensive field notes. A total of 38 classroom observations were conducted at various times during the two terms. These observations were done from the point of view of a nonparticipant observer; I tried to keep myself apart from the classroom activities as much as possible. The purpose of the observations was to gain a deep understanding of the classroom environment and the teaching behavior that represented the instructor's practice. I tried to see how the instructor's actions and interactions aligned with his or her conceptions. Each observation was of a full lesson ranging from 50 to 110 minutes. During the classroom observations, I focused on what (and how) computing technology was being used (by both instructor and students) and the classroom dynamics with or without computing technology. Combining interviews with document analysis and observations of the research participants' actions and interactions allowed for a holistic interpretation of the calculus instructors' conceptions (Bogdan & Biklen, 2002). A timeline of these data collection activities is given in Table 1 and a detailed timeline for data collection is given in Appendix C on page 189.

Table 1  
Timeline of Data Collection Activities

Date	Activity
August 14, 2008	Survey administration in both institutes
August 25, 2008	Participants recruited
September 5–18, 2008	First interview conducted with all participants
September 7, 2008–April 12, 2009	Classroom observations (38 total)
October 16–31, 2008	Second interview conducted with all participants
December 18, 2008–January 19, 2009	Third interview conducted with all participants
March 15, 2008–May 1, 2009	Sharing interview scripts with research participants

## Data Analysis

Data analysis “is the process of bringing order, structure, and meaning to the mass of collected data. ... Data analysis is a search for general statements about relationships among categories of data; it builds grounded theory.”  
(Merriam, 1998, p. 111)

The data collection process for this research study was extensive. As a researcher, I also wanted to engage in a learning experience. Thus, in this study, the data analysis process was not a discrete phase of research; rather, it was an essential part of the design and data collection (Bogdan & Biklen, 2002). The main goal of the analysis was to extract the essence of the calculus instructors’ conceptions of using or not using computing technology in teaching and learning calculus so that the essence could be used to communicate and to explore the meaning of those conceptions. I looked across the data to identify the calculus instructors’ conceptions (Glaser, 1998).

The grounded theory approach guided the analysis of the data (Glaser & Strauss, 1967), and the analysis was written up using methods outlined by Creswell (2003). The data analysis process, furthermore, was expanded and extended beyond giving mere descriptions of the concepts. I provided the essential link between the data and concepts, which resulted in a theory generated from the data (Glaser, 1998). The data analysis generated by the identification of coding units reflected the areas of concern from the research questions, the categorization of concepts that emerged, and the development of a theory. The first step was to identify the coding

units that reflected areas of interest. The initial coding units were the philosophy of mathematics, the philosophy of mathematics education, the philosophy of technology, and the role of computing technology in the instruction and the study of calculus. Some examples of these roles included providing a method of demonstration or a tool of investigation, relieving the tedium of symbol manipulations, and exploring complex ideas prior to gaining comprehension.

The coding units were compared across all interviews and field notes for evidence to support the descriptions and hypotheses that addressed the research questions. Strauss and Corbin (1998) define *coding* as a process such that “data are fractured, conceptualized, and integrated to form theory” (p. 3). The collected data, therefore, were systematically broken down and organized into manageable chunks to allow the abstraction and explication of the calculus instructors’ conceptions. As categories became more apparent and discreet, I reevaluated them to identify other possible connections or explanations in the data (Merriam, 1998). In this process, I tried to delineate the relationships between categories sufficiently to reach theoretical saturation—the state in which the researcher “makes the subjective determination that new data will not provide any new information or insights for the developing categories” (Creswell, 2003, p. 450). As the data analysis progressed, categories became saturated through comparison and verification of concepts and incidents (Glaser, 1998).

I also used the constant comparative method. According to Bogdan and Biklen (2002), the constant comparative method “explores differences and similarities across incidents within the data currently collected and provides guidelines for collecting additional data” (p. 493). Thus, the data analysis process involves explicitly comparing each incident in the data with other incidents appearing to belong to the same category and exploring their similarities and differences (Glaser & Strauss, 1967). In the analysis, I checked the tentative hypotheses for similarities and differences by constantly comparing them with other hypotheses, emerging and evolving categories, and developing theories. Through this process, I was able to see where gaps existed in data collection and which categories needed to be clarified.

As the analysis progressed, I sought to move beyond providing mere descriptions, and I focused on creating relationships among the categories. Glaser (1992) warns that many researchers who claim to use grounded theory stop once they have rich descriptions of the concepts identified in their data; they fail to conceptualize their data. Conceptualization in grounded theory must “be done as a careful part of theory generating and emergence, with each concept earning its way with relevance into the theory” (p. 24). According to Strauss and Corbin (1998), theorizing is the process of developing a theory that accounts for much of the obtained data.

### **Issues of Objectivity, Validity, and Generalizability**

In qualitative research, a number of procedures can be applied to enhance the credibility and rigor of an educational research study’s findings: prolonged engagement, participant validation, data triangulation, peer debriefing, negative case analysis, and clarification of researcher bias (Creswell, 2003; Merriam, 1998). To maintain credibility and to enhance the legitimacy of the research findings, I employed several strategies: prolonged engagement (over the course of 9 months), working with two peer debriefers, data triangulation, participant validation, and multiple observations (38 in all). At first, I tried to attain credibility in the study by locating my role as a critical interpreter and being consistent with practices in acquiring, indexing, and coding data. I had two roles in the data analysis process. Although my initial orientation was through an uncritical exploration to gain a descriptive understanding of instructors’ conceptions, during the process of data analysis, my role switched to that of a critical interpreter (Bogdan & Biklen, 2002).

Furthermore, I also worked with two peer debriefers (two recent graduates of mathematics education doctoral programs) to build procedures for coding and analyzing the data, in order to offer the opportunity for discussion of findings and possible researcher biases. Sessions were scheduled with each peer debriefer to examine coded data and allow for probing questions and different explanations or alternative coding of the data (Creswell, 2003; Merriam, 1998). With extended engagement over 9 months, I also tried to develop trust between the

research participants and me as a researcher to reduce the likelihood that they would exhibit contrived behaviors. Furthermore, being present for such a long period of time in the participants' classes and spending a substantial amount of time with the participants helped me to ensure that I would gain more than a snapshot view of the instructors' conceptions.

Once the research findings were revealed, I tried to implement participant validation as much as possible by taking the findings back to the participants for elaboration, correction, and accuracy. I also used data triangulation by trying to verify results and conclusions from multiple data sources such as observations, field notes, and interview transcripts. This process allowed me to be as consistent as possible in the methodology as well as data collection and analysis.

With respect to the educational implications of these research findings, the reader must judge, keeping in mind that “drawing on tacit knowledge, intuition, and personal experience, people look for patterns that explain their own experience as well as events in the world around them” (Merriam, 1998, p. 211), or as Crotty (1998) puts it, “[Research findings are] suggestive rather than conclusive. They will be plausible, perhaps even convincing, ways of seeing things—and, to be sure, helpful ways of seeing things—but certainly not any ‘one true way’ of seeing things” (p. 13).

## **CHAPTER 4: TEACHING CALCULUS USING COMPUTING TECHNOLOGY**

### **Joe's and Dorothy's Conceptions of Mathematics and Learning Mathematics**

Joe had been teaching college level mathematics for more than 28 years. He had taught a variety of courses, ranging from Learning Support to Linear Algebra. While teaching, Joe had participated in several curriculum development projects and had served on several college committees, including Faculty Senate and Admission. Furthermore, he served as the faculty advisor to the mathematics club at his college for the previous 4 years. He had also made several mathematical research presentations at national and international conferences and reviewed articles for publishing companies and mathematical journals.

Joe defined mathematics as a quasi-empirical discipline: "It is not the same as physics, but it is more akin to an empirical science than we mathematicians want to admit" (Interview 1/ September 12). To Joe, mathematics essentially involved an understanding of logical structures and learning how to solve problems that have been modeled mathematically. The process of finding solutions to problems brought him both excitement and satisfaction. He described the problem-solving process as a "challenging and exciting journey where the mind's creativity can be harnessed to produce a solution" (Interview 1/ September 12). Joe believed that doing mathematics involved carrying out laborious, deliberate experimental work and "trying to understand the problem, exploring ways to approach the problem, performing calculations to see patterns, and working through examples for finding some useful generalizations" (Interview 1/ September 12).

Dorothy had a similar amount of teaching experience as Joe; she had been teaching mathematics at Fairway College for 14 years. She received her Ph.D. in Topology from a university in the Southern U.S. and started teaching in the same region. She had taught a variety of courses ranging from Learning Support to mathematics content courses for education majors. While teaching, she had also participated in several curriculum development projects and taught several online mathematics courses. At the time of data collection, Dorothy was teaching calculus and college algebra classes at Fairway College.

Dorothy was always fascinated by the connections between mathematics and other disciplines, and she described mathematics as “a multifaceted discipline” (Interview 1/ September 11). Following that line of reasoning, she compared it to an octopus because an octopus has many arms that are able to cover multiple areas and can be applied to many different tasks. Similarly, she stated that “math has many uses beyond mathematical settings” (Interview 1/ September 11). For Dorothy, mathematical ability involved more than being able to carry out specific rule-based procedures in routine situations; rather, it required the ability to think through and solve mathematical problems. From Dorothy’s perspective, students should be able to identify and solve kinds of mathematical problems, check proposed solutions to problems, and interpret and validate the solutions.

Dorothy and Joe both believed that the introduction of computers had provided a new and powerful tool for doing mathematics. The main factor that helped them to develop such a positive conception of computing technology was rooted in their observations of how the introduction of such technology, especially computers, considerably benefited many areas of mathematical research. Joe said that computers provided a completely new tool in doing mathematical research and stressed that they were continuing to have “a significant impact on the

way in which many mathematicians carry out their research” (Interview 1/ September 12). Joe claimed that the very existence of computers had especially widened “the scope and dimensions of mathematical explorations” that mathematicians could conduct (Interview 1/ September 12). Both Dorothy and Joe were convinced that the availability of computers relieved many mathematicians of a great many calculations and encouraged them to attack problems that they could not do before. Joe claimed that with the use of computers, mathematicians were able to “carry out calculations in a very short time period which would require a lifetime” (Interview 1/ September 12), thus enabling mathematicians to make mathematical discoveries by observations before the validity of their conjectures had been established. Dorothy expressed the same idea by saying the computer had made it possible to experiment with large data sets and had helped mathematicians “to see patterns and structures of the data to develop mathematical conjectures” (Interview 1/ September 11). Although they both saw how the use of computers had had an enormous effect on applied mathematics, Joe also claimed that the computer had significantly changed the conception of what is a satisfactory solution of a mathematics problem. As an example, he cited the use of computers in the famous proof of the Four Color Theorem.

Joe’s and Dorothy’s conceptions of learning mathematics derived from their major epistemological belief that engaged learning was active learning. They both identified active student engagement as vitally important for successful mathematical learning. If students are going to understand and learn mathematics, they must be engaged in the learning process as it unfolds. Joe expressed the need for students to be active in their learning process by stating, “I always remind students to be active, to be engaged-do more than just watch” (Interview 1/ September 12), and Dorothy expressed the same idea by saying, “There is one effective way to



learning mathematics and that is by doing it. This will always be my point of view” (Interview 1/ September 11).

Joe and Dorothy both saw the process of problem solving as an important tool for getting students to be active in their learning. When they talked about problem solving, they related it to the process of learning mathematics: Joe stated that solving problems was not only an end, but also a means for learning mathematics because “a consequence of the [mathematical] understanding is to be able to solve problems” (Interview 1/ September 12). He also saw the process of problem solving as a vehicle to help students become independent learners. The active characteristic of his teaching was that the students should have found answers to the questions by using their own faculties. Joe portrayed learning mathematics as similar to learning how to ride a bicycle and believed that the only way one could learn mathematics was by conducting mathematical explorations through problem solving: “You can’t teach a child to ride a bicycle by telling, and you can’t teach a student to do mathematics by lecturing” (Interview 1/ September 12).

Although Joe considered active learning to be of the utmost importance, that did not mean that he believed lectures were unimportant. In fact, he always analyzed the way in which he presented information in order to ensure that he was effectively teaching students. For example, whenever students did not perform as well as Joe thought they should, he did not necessarily blame them. He was willing to consider that the way he taught the material might have been a cause of the students’ lack of success. He looked for reasons students did not understand and considered that he might be one of those reasons, instead of assuming that the students did not try hard or study. Once, for example, when a group of his calculus students did not grasp the topic of related rates as well as his previous classes had done, Joe commented, “I

don't know if it was the group I had the year before that was just a little bit sharper, or whether I just did a better job teaching it, or whether—I don't know" (Interview 2/ October 28). He was willing to admit that multiple factors might affect the transmission of information and students' understanding of that information.

Dorothy also saw the process of problem solving as an important medium to get students to be "excited about mathematics and develop their confidence to do significant mathematics" (Interview 1/ September 11). But she also warned how accomplishing that aim required the careful selection of problems. Dorothy complained about the way many instructors worked examples in class similar to those they would assign for homework, and said that approach did not challenge or excite the students. For successful mathematics learning, Dorothy claimed that the instructor should have given carefully chosen mathematical problems based on each student's cognitive development and mathematical knowledge base. She provided an analogy of crossing a stream for guiding students through problem solving and fine-tuning the difficulty level of problems. To Dorothy, the selection of problems was akin to placing rocks for crossing a stream. If the instructor placed the rocks very close together by selecting easy problems, then "crossing the stream was nothing more than an exercise" (Interview 2/ October 26). If the instructor placed the rocks too far apart by selecting very difficult problems, then most students would lose their confidence and would "fall into the stream" (Interview 2/ October 26). Just like the adjustment of the distance between stepping stones, the difficulty level of mathematics questions must be carefully considered so that each student is successfully challenged. Thus, the instructor should be adjusting the difficulty level of questions based on each student's current mathematical knowledge; this adjustment might necessitate adding a rock for one student, but removing a rock for another.

Dorothy's focus was on ensuring that all students were learning, no matter what level they were at. She defined *learning* as “the acquisition of new knowledge and the application of that knowledge” (Interview 1/ September 11). She thought it was important for students to be able to use the mathematics they learned in class to describe real-world phenomena, and she believed that such use would promote understanding. It was exciting to Dorothy when students saw a reason for learning mathematics, and she believed that using applications of mathematics would help students understand the mathematics better. For example, she used a motion detector along with a CBL (Calculator-Based Laboratory) for an activity in which students walked in front of the motion detector, and a graph of time versus distance was displayed. She said the activity would lead students to meaningful mathematics learning because it was showing “the motion of walking away from the wall and getting into a line of positive slope; walking toward the wall and getting into a line of negative slope” (Interview 2/ October 26).

Dorothy and Joe both wanted their students, in learning mathematics, to be active and independent by developing mathematical competence through meaningful activities. They both repeatedly told their students that getting the answer right was not critical; rather, developing an understanding of the problem-solving process was more important. Furthermore, they also thought that students' algebraic backgrounds were not determinants of their calculus learning. Joe claimed there was a large range of levels among the students in the class, and “the instructor cannot take for granted that all of the students have all of the necessary algebra skills” (Interview 2/ October 28). Referring back to her experiences with students, Dorothy claimed, “I have students now, and have always had students, who are very competent with all their algebraic manipulations. And sometimes those students struggle with calculus, and sometimes they don't” (Interview 2/ October 26). Although both Dorothy and Joe admitted that there were definitely

students who were held back by the level of their algebra skills, they also contended that if a student had the desire to learn, he or she could practice and improve algebraic skills and concepts.

### **Joe's and Dorothy's Conceptions of Teaching Calculus**

Joe and Dorothy did a considerable amount of planning and thinking about their instruction. They firmly believed the amount of time a teacher put into preparation would directly translate to how the students learn. For Joe, teaching provided an opportunity for continual learning and growth, even after years of experience: "I have been always interested in reflecting on what I was doing or thinking and in thinking about ways to improve my teaching" (Interview 2/ October 28). According to Dorothy, successful teaching was a process of experimentation in which "the instructor experiments with ideas and finally distills out the best learning experience for the students" (Interview 2/ October 26). They both claimed that having a genuine passion for the subject matter was one of the single most important components of effective mathematics teaching, as it would lead to thorough preparation, continuous evolution of teaching skills, and the pleasure of watching students learn. But above all, Joe and Dorothy both believed that teaching required openness to change; the instructor should continually examine his or her teaching techniques and experiment with ways to become a more effective teacher by integrating technology, adapting practices to address the needs an increasingly diverse student body, understanding different learning styles, and incorporating various assessment strategies.

Joe thought that the instructor should definitely build a positive rapport with students while still maintaining healthy and respectful boundaries. The instructor should be sensitive to students' feelings and show respect by not dismissing any information or a particular step in algebraic simplification. Over time, Joe had learned to be more sensitive to his students' feelings.

For example, he tried to choose his words carefully, in recognition that his students' confidence could be affected by a thoughtless word choice: "I have learned to not say 'easy algebraic steps,' because it might make a student feel bad if they don't know the algebra. Students react very negatively if they are made in any way to feel that their knowledge is inadequate" (Interview 2/ October 28).

Joe tried to use the content of his courses to promote self-awareness of learning; students needed to be aware of themselves as learners and develop confidence in their ability to tackle learning tasks on their own. One of his hopes as an educator was to instill a love of learning mathematics in his students. For Joe, teaching was more than transmitting knowledge: "Teaching is about inspiring students to discover their potential" (Interview 2/ October 28). As a professor, Joe believed he had the opportunity to affect the lives of students, and he took that role seriously. He wanted his students to enjoy and appreciate mathematics, and he wanted to extend the enjoyment of mathematics beyond the small circle of mathematically talented students. Joe eagerly compared doing mathematics with performing music. Although few people are gifted enough to compose music, many people can understand and enjoy it. He believed the number of people who could understand and enjoy mathematical ideas could be increased if their interest was stimulated and their aversion to mathematics was eliminated. To dispel the attitude that mathematics is very difficult, Joe shared his own passion and learning experiences in mathematics with his students: "If I am very open and maintain an open dialogue with my students, it is much easier for me to achieve these things since students usually reciprocate" (Interview 2/ October 28).

Joe's image of mathematics as a quasi-empirical discipline was the main influencing factor that shaped and directed his calculus teaching. He particularly enjoyed the problem-

solving aspect of doing mathematics and wanted to help his students learn calculus through problem-solving activities: “Problem solving is a great interest of mine. In class, I generally point out the students’ particular skills that will help them in their problem solving” (Interview 2/ October 28). With the implementation of a problem-based calculus curriculum, he wanted his students to see that doing mathematics involves carrying out challenging and deliberate experimental work.

Joe believed that, with the help of problem-solving activities, his students could develop more confidence in doing mathematics because they could figure things out for themselves and would also, therefore, enjoy his calculus class. In Joe’s opinion, students were not passive receivers but active builders, and his role in teaching mathematics was to facilitate student learning through problem-solving activities. He stated that all he was “concerned with is that they [students] know how to apply the information to simple situations” (Interview 2/ October 28). When Joe assigned a mathematics problem, he wanted his students to have enough confidence to work with the problem until they were able to find the answer. He liked to use problem-solving activities to provide ample opportunities for him to address students’ needs regarding learning and, thus, to be able to cultivate and sustain success. Problem-solving activities helped him “to examine and understand the way in which students think through a problem” (Interview 2/ October 28). Through active observation and questioning when students were working on a problem-solving activity, he was able to find out about their prior knowledge, and consequently, he could design subsequent tasks or pose questions designed to guide his students’ learning effectively.

Joe believed that his students’ ability to solve calculus problems demonstrated their mastery of the concepts: “If they [students] understand the principles behind that portion of the

course, then they are going to be able to solve those problems” (Interview 2/ October 28). In his calculus classes, Joe presented his students some simple problems at the beginning of the course, followed by more complicated problems. If the students had difficulty with complicated problems, he tried to break the complex problems into smaller parts, believing this strategy would help the students see where to go with the problem: “Sometimes they [students] would look at complicated problem and [have] no idea where to start. It isn’t lack of knowledge. They simply didn’t know how to apply what they learned” (Interview 2/ October 28).

Joe considered himself responsible for developing a supportive environment in the classroom, and he regarded the learning process to be a team effort between himself and the students. Through problem-solving activities, Joe wanted to lead his students to explore, inquire, synthesize, and report their findings. His calculus classes were interactive, with reporting and questioning shared between him and the students. His teaching focused on what the students did and discussed and consequently came to know:

I’m not interested in having lectures just merely being the presentation of a whole bunch of information and something to be gotten through. The real value I think that a lecture can have is to provide a sense of excitement when students really start to investigate stuff. (Interview 2/ October 28)

Rather than developing a curriculum aimed at the typical student, Joe also thought instructors should modify their calculus instruction to meet students’ readiness levels, preferences, and interests. Joe noted that developing a curriculum around student interests fostered intrinsic motivation and stimulated the passion to learn. The predominant belief that guided Joe’s teaching was his concern for the welfare of the students. This concern was reflected in his encouraging and supportive attitude. In his calculus classes, he did not dismiss students’ questions with a short yes-or-no answer, believing that the way he responded to students’ questions was integral to the effectiveness of his teaching style. When he was teaching, and a

student asked a question, Joe took a moment to determine the best response he could give to the student before he began to answer the question. The quality of his responses made the students feel as though they had contributed to the knowledge being presented in the classroom. Joe regarded the students' questions as a valuable part of their learning process, and he believed the students deserved respectful treatment in the classroom, even when their questions might be tangential to the subject at hand.

Joe also emphasized the importance of the teacher's responsibility to ask effective questions designed to guide the students to further their mathematical understanding and also encourage them to keep working on the task. In addition, Joe did not settle for cursory responses to the questions he posed. He continued with follow-up questions that were intended to deepen the discussion and set expectations. He saw the teacher's role as that of a guide who provided access to information rather than as a primary transmitter of information. The instructor needed to "provide opportunities for students to express, discuss, and argue about mathematics" so that they could construct their own knowledge (Interview 2/ October 28). Joe strived to create an active, collaborative learning environment filled with curiosity and inquiry in which participants were both the students and himself, and where the students could "discover knowledge rather than be passive recipients" (Interview 2/ October 28).

Joe wanted to develop both ability and confidence in students so that they could learn how to solve problems: "I came to accept that one of my tasks as an instructor was helping students to develop lifelong learning skills and confidence" (Interview 2/ October 28). Above all else, Joe enjoyed the moments when the students realized they were in control of their own learning. To Joe, part of being in control of one's own learning, however, included the ability to seek knowledge while working as a group. To that end, he encouraged collaboration and



cooperative learning; he had students work individually or in teams over time to develop solutions to problems. He urged the students to be personally involved and tried to develop a classroom community. Seeing students working together to come up with solutions to mathematics problems gave him great satisfaction. He said, “It is fun to see students come up with an answer themselves. Especially when a student doesn’t think he is going to be able to do a certain problem and is finally able to answer it correctly” (Interview 2/ October 28). Seeing the excitement in students while they actively constructed their knowledge supported and encouraged Joe’s teaching.

Like Joe’s teaching, the object of Dorothy’s teaching was identifying the needs of her students and basing her teaching upon meeting their needs. She recognized that the students had differing learning needs, and it was her responsibility to help the students realize those needs. For Dorothy, the instructor should engage the students with the mathematical knowledge with the intention of helping students develop their conceptual understanding. In her approach to teaching calculus, the instructor’s purpose was to enable the student to learn the material through practicing the disciplinary knowledge, engaging with the material in ways similar to that of the academic practitioner.

Dorothy summarized good mathematics teaching as follows: “If the students learn what they want to learn, then I have done my job” (Interview 2/ October 26). Dorothy believed that mathematics instruction, especially calculus teaching, should be tailored to students’ needs. She said that instructors should recognize the diversity in the student population, and therefore the complexity and presentation of the material should be adjusted to best meet students’ needs: “Every time I teach, my attitude is first to look at the audience, find out who they are, what’s

their background, what's their level of expertise and knowledge, what are their objectives, and ask myself, 'What do I want them to accomplish?'" (Interview 2/ October 26).

Dorothy said that the traditional one-size-fits-all instructional approach to teaching calculus did not really serve the majority of students; to the contrary, it created a barrier for students who would succeed in majors such as biology or business. Dorothy noted,

Calculus should not become a barrier to students in those other majors just because they have to take the course with engineering, science, and math majors. Those students just need to understand the concepts of the problems, not all the nitty-gritty details like an engineering or math student would. (Interview 2/ October 26)

Dorothy also thought that the traditional calculus sequence lacked an applied component, which severely limited its usefulness to those students who were not proceeding to physics or mathematics.

In her teaching, Dorothy wanted to create a sense of connectedness between her students, mathematics, and the real world. One of the main purposes of her teaching was to persuade her students of the importance of mathematics so that it could enhance their lives: "I will teach what I think would benefit them most" (Interview 2/ October 26). Dorothy was not happy with the common rationale that *it is required* for their academic discipline to take her calculus class. "I hear it all the time, but I don't like it very much" (Interview 2/ October 26). One thing as an instructor she thought she could do was encourage students to see how mathematics fits into life experiences and various career choices. Dorothy tried to help the students learn mathematics, especially calculus, by applying mathematical concepts to their own particular discipline. Dorothy suggested that the students would be more engaged if the instructor used real-world problems instead of hypothetical problems or physics problems. For example, she claimed that the life science majors needed to see how calculus concepts could be used to analyze population growth models, membrane diffusion, enzyme kinetics, and Le Chatelier's Principle for chemical

equilibrium. She offered an example to illustrate her point: “Last year, I had a lot of pharmacy majors, and many of them worked in drugstores. We were learning about exponential growth and decay, so I put a question on the test about how much anesthesia a dog would need in order to be in surgery for 45 minutes” (Interview 2/ October 26).

According to Dorothy, an emphasis on real-world problems in teaching calculus also helped to pique her students’ interest and increased their conceptual understanding. She believed that the use of real-world problems could provoke and facilitate meaningful mathematical learning since “many students were not convinced mathematics was something other than an academic hurdle” (Interview 2/ October 26). Dorothy also claimed that students were more motivated to learn mathematics when these connections were explicitly demonstrated in the classroom. She said that the presentation of the connection between mathematics and other academic disciplines could dispel the misconception that “doing mathematics was doing calculations and taking exams” (Interview 2/ October 26). She believed that mathematics and real-world connections should have been made explicit in all aspects of her calculus teaching—the classroom, homework, projects, and exams. Dorothy was convinced that her approach to teaching calculus was working and stated, “I seem to be going a lot more into making it relevant to them more than just delivering the facts” (Interview 2/ October 26). One example of Dorothy’s efforts to reveal these connections happened around Valentine’s Day. She lectured on polar coordinates and then asked her students to create a valentine card by plotting  $r = 1 - \sin\theta$  in polar coordinates, which produces an image that is similar in shape to a Valentine’s Day heart.

In an effort to enhance her instruction, Dorothy incorporated various kinds of technology, including Maple, a graphing calculator, a SMART Board, and online animated visuals and self-assessment tools. In class, she used an on-screen projector display about half the time when she

was demonstrating concepts and conducting mathematical investigations. Dorothy thought one of the main advantages of computing technology was to provide immediate visual and mathematically meaningful consequences: “[Technology] helps to get across visually a lot of things that are very difficult to describe using words” (Interview 2/October 26). She used visual aids, explorations, and active learning modules to contribute to the development of students’ conceptual understanding. She believed that the visualization power of technological tools especially enhances mathematical concepts and can create genuine interest in mathematics. For example, Dorothy used animations to teach the volume of revolution to show how the volume is forming, or she sometimes used interactive Internet applets illustrating the formal definition of the limit with moveable  $\delta$ ’s and  $\epsilon$ ’s. For each section of the text, she provided a diverse array of online resources as supplementary material. Dorothy said that her students viewed these resources as value added to the course and responded positively to using them.

Dorothy claimed that the use of technological tools helped the students collaborate with each other in the process of learning mathematics. In her online and traditional calculus classes, she routinely observed how her students were working collaboratively on class projects and homework through the Internet, email, and instant messaging. She understood that learning mathematics was a collaborative effort and stated that “rather than laboring alone on homework and projects, students can work in small groups at any time, and wherever they happen to be” (Interview 2/ October 26). She claimed that the very existence of various instructional technological tools would require getting beyond the current system of information and delivery. Students could be asked and empowered to master more basic material online at their own pace, and the classroom could become a place where the application of that knowledge could be honed through mathematical experiments and discussions with her. In making a case for all of this

collaborative effort, Dorothy stated that the world did not care what students know: “The world only cares, and will only pay, for what you [students] can do with what you know” (Interview 2/ October 26). Although Dorothy still saw a huge value in the traditional college experience and the teacher-student and student-student interactions it facilitated, she advocated a blended model that combined online lectures and demonstrations with a teacher-led classroom experience as the ideal for calculus teaching.

Dorothy described her role as a mathematics instructor as similar to that of a coach. Just like a coach and her players, Dorothy and her students shared a responsibility for the learning process when they were together in the classroom. Like a coach telling her players what she expected them to do and correcting her players’ mistakes, Dorothy determined the learning outcome and corrected students’ misunderstandings. A coach not only instructs players, but also designs practices and the game plan, just as the instructor does with lesson plans. Just like a coach, Dorothy provided students access to hands-on activities and allowed adequate time and space to use materials that reinforce the lesson being studied, creating an opportunity for individual discovery and construction: “My job is to provide them with an environment in which they can learn. Of course, I should ensure that what they are trying to learn is within their grasp” (Interview 2/ October 26). As a coach helps players improve their skills to the maximum of each player’s abilities, Dorothy wanted to help each of her students reach his or her full potential for understanding mathematics. She described her responsibility as working with every single student, regardless of skill level, with the student’s improvement as her goal. Dorothy knew that good instruction, like good practice, needed to be challenging to encourage students to think and talk about their ideas. The instructor, like a good coach, had to challenge all students by pushing them to move beyond their comfort zones. She stated:

It is rewarding to set high goals for the students. I think it is a big mistake when [instructors] water down classes. I think that is a terrible disservice to the students. I give no partial credit on homework problems, instead opting to let the students rework incorrect answers for full credit. This forces students to identify their mistakes and come to my office for help. (Interview 2/ October 26)

Both Joe's and Dorothy's teaching were aimed at focusing on their students' conceptions of the subject matter rather than their own conceptions. They saw their role as helping their students develop their mathematical understanding. They also thought that the instructor should assess students' mathematical learning at various points and needed to revise or modify learning goals, instructional methods, or content when necessary. They both considered that success in teaching mathematics depended on motivating students. According to both professors, the main task for instructors was to arouse interest and enthusiasm in learning and a love for mathematics so that students would be seduced into learning. Whereas Dorothy used real-world problems from students' academic disciplines, Joe tried to accomplish the same goal through a problem-based teaching approach.

### **Joe's and Dorothy's Experiences of Teaching Calculus**

In the mid-1990s, Joe participated in several curriculum projects dealing with integrating computing technology into calculus classes. Those projects were instrumental in formulating Joe's views on integrating technology in the classroom and fundamentally changed the way that he taught. The first curriculum project Joe took part in was to teach an experimental version of a calculus lab, in which he used graphing calculators. That curriculum project not only helped Joe to become acquainted with computing technology, but also helped him to learn how to use them in a manner he considered to be effective for teaching calculus.

The student feedback Joe received during his experimental section of calculus indicated that his students thought the graphing calculator was easier for them to use than the computer

software Maple. Joe liked the idea that his students had the calculators at their disposal outside of class and that they could use it for their homework. He said that initial experiment was promising but far from a complete success story. He found that “it was still difficult to do substantial things. We didn’t come close to exploiting the full power of the calculator” (Interview 2/ October 28). Joe concluded that the projects he created were often difficult for students because he was trying to cram too much into each project. Joe reflected on his past projects: “If you look at some of the projects that I created in the very first year, you would find that they are designed to push beyond the boundaries that students normally go” (Interview 2/ October 28). Joe determined that his first few projects were overly ambitious, and he decided to adjust the difficulty level to more closely match the level he thought was appropriate for his students. In addition, Joe listened to his students’ complaints that those first projects were not very relevant to their academic disciplines, and he created a new set of projects that his students found more relevant and easier to engage with.

Joe tried not to be disheartened by that first calculus lab project, even though he claimed that it was relatively unsuccessful. Joe reported that many students thought the technology was too difficult to use, and some students used the technology to cheat (e.g., finding the maximum or minimum of the functions by using computers instead of finding derivatives) in ways with which Joe previously did not have to be concerned. However, Joe reported that he learned many valuable lessons during that first attempt. Through the initial experiment, Joe learned to consider his students’ background and technological competence in his technology integration decision. Ultimately, although the initial experiment was not entirely successful, Joe decided to use the TI-83 graphing calculator in his calculus classes. Joe explained his reasoning:

Many students have worked with TI-83s in high school, and are somewhat proficient with them. There are perhaps 20–25% of the students who have not used them, so I knew I

would have to explain how to do various kinds of procedures, such as graphing a function, zooming in, or finding roots. (Interview 2/ October 28)

During this second integration attempt, Joe was pleased with the feedback he received from his students regarding their experiences learning with the graphing calculators. In class projects, Joe's students used their calculators to find zeros or graph functions. Joe believed his second technology integration attempt was successful because he took his students' technological backgrounds into account when selecting the computing technology tool he would use, and when preparing the class projects. Joe had learned that it was more convenient to use a technology tool that his students could use anytime they wanted instead of being limited to a software program such as Maple, which was accessible only in the school's computer lab.

Joe's experiments with technology led him to conclude that for computing technology to be truly integrated into teaching and learning, it must become an integral part of the course. He also determined that to achieve the best possible results, he needed to allow his students to be actively involved in their own learning. Joe was willing to undertake the additional time and effort to figure out the best way to incorporate technology, and he claimed the results demonstrated to him that his extra efforts were quite worthwhile. Joe reported that his students were able to perform tasks using higher order concepts than they would have been able to do without the calculators, which, to him, indicated significant learning gains for the students. As a result of those experiences, Joe affirmed that integrating technology into the classroom could enhance and transform the learning process, and he continued to embrace the use of technology in his classroom.

Dorothy's enthusiasm for using computing technology in calculus teaching started a decade before. She was inspired by a colleague's presentation that demonstrated the use of Internet resources in teaching. That demonstration intrigued her, so she began contemplating



ways in which various Web-based tools could serve her teaching needs. Initially, she considered using computing technology as a way of providing information more easily and with better visual representations than she could draw on the blackboard. As she explored further, Dorothy became impressed with how interactive technology could potentially enhance feedback opportunities. When she used technology to illustrate a concept, she found that her students had greater opportunities to formulate questions and point out specific elements they did not quite comprehend. Through this more informative feedback, Dorothy was able to adjust her instructional approach in a timelier manner than before. She recounted her path of experimentation as one that began with creating simple hyperlinks for her students to follow for further demonstrations, but that eventually transformed into a full-fledged online course that she has taught several times. When planning the online class, Dorothy initially structured it to be “a good replica of what happens in the classroom” (Interview 2/October 26). Eventually, however, she perceived this approach to be unnecessarily restricting.

Through her online teaching, Dorothy experienced what she called a paradigm shift, one that led her to the realization that, regarding the use of educational technology, she needed to change her beliefs about how to teach. Dorothy concluded that instead of adapting the technology to the traditional classroom environment, she should use the technology to create a completely new classroom experience, both for herself and for her students. Although the transformation began gradually, Dorothy noted, “as I get more into [using technology], it’s become less of an extension of a traditional classroom and more of a challenge to think of different ways of doing things” (Interview 2/October 26).

Dorothy’s decision to teach an online business calculus class turned out to be a major turning point in the way that she used technology to teach all of her classes. Not only did the

process of creating the course forced Dorothy to gain technical knowledge about various computing tools, but it also stimulated her to reflect on the potential educational impact of teaching mathematics in a new way. During her first online business calculus class, Dorothy was surprised by the quality of online discussions and the depth of the mathematical dialogue occurring among the students. Because she did not see similar discussions taking place in her classes held in traditional classrooms, Dorothy attributed the depth of mathematical conversations to the online format of the new course. As a teacher, Dorothy said that she always wanted her students to be active participants in their own learning process, but she soon realized that succeeding in an online class requires participation from students in a way that the traditional classroom does not: “It’s only in the online classes that they really have to be actively engaged in learning. They don’t have a choice. I’m not standing in front of them and teaching calculus from scratch. They need to learn on their own” (Interview 2/October 26). Dorothy reported that she enjoyed her online mathematical conversations with students, and she believed that students enrolled in online courses must focus their mathematical thinking more than they would have to with face-to-face instruction. She suggested that communicating mathematical concepts and questions in writing was more difficult than communicating verbally because it required a certain amount of thinking through to simply formulate a good question:

In an actual class, a student can simply point and say, “I’m having a problem here.” When the teacher and students are not physically in each other’s presence, then the students must do more than just point to a problem. They are forced to be more descriptive in asking a question, and this leads to greater understanding and more thoughtful questions. (Interview 2/October 26)

This learning experience changed Dorothy’s conception of teaching as well. She struggled at first with the increase in the amount of time required to monitor, respond to, sustain, and manage incoming and outgoing course communications. Dorothy said she was wrong to

think initially that when the online class was created, the bulk of her job was over. As Dorothy had since learned, “There is an enormous amount of time commitment required from both the student and the teacher. My colleagues didn’t know that I’ve been spending far more time reading and responding to students’ email messages than I would have spent on a lecturing course” (Interview 2/October 26). Although Dorothy admitted that she used to resent the time required to keep up with the needs of her online students, she eventually accepted the time investment after she saw the payoff in the performance of her students.

Participating in different calculus curriculum projects made both Joe and Dorothy engage in reflection that led to what they saw as better calculus teaching. Their reflection focused on learning from and about their experience of teaching, and then linking it to their future actions. The main factor that stimulated such a change was their desire or motivation to value teaching and to be good at it. During these experiences, they showed a willingness and an ability to take risks in their actions and to do things differently. They discovered how to guide students from the sidelines rather than being the sage on center stage. Joe explained this transformation: “My teaching style has changed. Now I set problems for the students and let them explain how they should go about doing it, and then I correct them if necessary” (Interview 2/ October 28). Dorothy summarized a similar transformation: “Before, I told them how to do it. They learn better by explaining or experimenting by themselves than by me just telling them” (Interview 2/October 26). Both professors had learned that there were different styles and different strategies that they could use and that they should always be willing to try out new strategies and modify existing ones to suit their students’ needs in the course.

## **CHAPTER 5: TEACHING CALCULUS BUT NEVER USING COMPUTING TECHNOLOGY**

### **Lynn's and Ron's Conceptions of Mathematics and Learning Mathematics**

Lynn had 20 years of experience teaching college-level mathematics. She had taught various undergraduate and graduate level mathematics classes, and she believed her teaching style came from her own mathematical experiences.

In her calculus classes, she focused more on doing mathematical proofs and providing reasons behind concepts than on the applications of calculus concepts. Lynn described mathematics as a very powerful and elegant process that is similar to a beautiful golden eagle's flight—one can rise as high as one desires. Similarly, Lynn compared calculus to a peacock; calculus showcases mathematics by presenting “a beautiful display of some of the most fundamental mathematical thinking and methods” that are also scientifically very powerful (Interview 1/ September 12). In Lynn's opinion, calculus provided an open door to higher mathematics. It is primarily an analytical tool that represents the world in symbolic forms. Lynn stated that as an elegant intellectual achievement, “calculus can reduce complicated mathematical problems to simple but precise rules and procedures” (Interview 1/ September 12).

When teaching, Lynn emphasized practicing mathematical proofs, believing that the skills and thought processes involved in writing proofs is necessary for learning mathematics. According to her, proofs make the beauty of mathematics accessible to students, and the arguments found in proofs are easy for students to retain. She stated, “A mathematician does not learn about proofs per se, but he or she learns about mathematical concepts through proofs”

(Interview 1/ September 12). Thus, Lynn claimed that the study of proofs provided a student with some of the most effective mathematical techniques and ideas ever developed. She thought that the ideas found in proofs could also be a springboard for advanced concepts the student might encounter in future studies. Thus, proofs can serve as important tools for clarification, validation, and deeper understanding. Lynn claimed, “The only way to understand a mathematical result is to prove it yourself—find your own proof” (Interview 1/ September 12). She claimed that practicing proofs could provide a student with a developing ability to answer such questions as “How do we know that? And why do we believe this?” She believed that answering such questions could demonstrate true learning and understanding of mathematics. Lynn thought that the process of learning mathematics was just figuring things out: “Figuring out the meaning of definitions, ideas, and concepts to bring them into consideration” (Interview 1/ September 12).

Instead of using computing technology, Lynn preferred her students to use pencil and paper so that they could put their ideas clearly in writing, and then she could interpret them. Lynn believed that the only meaningful way of learning mathematics was to actually do mathematics by hand. She thought it was a mistake to teach calculus with computing technology without teaching with paper and pencil first. I was struck by the degree to which she stressed the importance of understanding mathematics through learning with paper and pencil and the intensity of her resistance to the idea of being taught to “press buttons.” She claimed most students had absolutely no experiential basis for understanding the abstract structure of mathematics, because they had not frequently worked with paper and pencil:

You study math gradually. First, you start at the bottom. You pick things up with your fingers and you do everything by hand. Eventually, you start to step back and examine what you have been doing. One cannot understand methods and concepts unless one has

a certain amount of experience of doing things with one's bare hands. (Interview 2/ October 28)

In Lynn's opinion, mathematics is a hierarchical subject that builds upon what one has already learned. Students cannot rise to a higher-level understanding without first having a solid foundation. She expressed that advanced concepts and ideas "cannot be approached until corresponding elementary and intermediate areas have been covered" (Interview 2/ October 28). As a consequence, Lynn argued that it is not feasible for students to be learning basic mathematical techniques at the same time that they are supposed to be using more advanced techniques in applications and in problem solving in their other studies. Students' knowledge gap prevents them from being able to learn calculus well if they are still struggling with basic concepts. Lynn further explained why students should have had a solid knowledge base and a well-developed skill set for learning mathematics:

[Students] don't even understand the order of operations, or they would use parentheses correctly. They square a binomial and get two terms instead of three. Students at the university entry level are supposed to master these topics, which are included at different grades, in the mathematics curriculum. (Interview 1/ September 12)

Like Lynn, Ron had been teaching mathematics for a number of years. He was in his 30th year of teaching, had received multiple teaching awards, and had been involved in some curriculum development projects at Fairway College. Also similar to Lynn, Ron remained critical and held strong views on the appropriate and relevant use of technology in calculus learning. Ron considered mathematics to be a connected body of knowledge and believed instructors need to make connections between topics in order to help students understand the bigger picture. Students needed to see that learning is connected and that mathematics can be applied in many different contexts. For successful mathematics learning, Ron explained, students

need to construct “an understanding of how mathematical ideas are related” (Interview 1/ September 19).

Although Ron knew that mathematics was a challenging subject that many people did not like, he was proud to be in the minority of people who enjoyed the subject. Ron believed that practicing mathematics was a form of self-growth, and he loved the challenge of understanding abstract concepts. He stated,

When I am doing mathematics, it feels as though what I am working on is real. You feel you can almost pull it into pieces and focus on each piece separately. Just like a puzzle; I like to put it back together. (Interview 1/ September 19)

According to Ron, mathematics defines everything happening around us: “Knowing mathematics opens one’s eyes to the laws of nature and offers entirely new experiences” (Interview 1/ September 19). Thus, if one wants to learn about nature, it is necessary to understand the language—to know mathematics. He believed that, with the help of mathematical knowledge, one can attain a deeper understanding of everyday life:

You don’t need to have mathematical knowledge to blow bubbles, but if you know mathematics, you realize that those bubbles are only round because that’s the most efficient energy form for them. Everything is mathematics, and mathematics is everywhere. (Interview 1/ September 19)

Ron believed the main purpose of learning mathematics was not about learning a series of facts but about training the mind to think. He asserted that the focus of a college mathematics education should be on teaching people how to think. If students were not trained to think, Ron believed, “the university has given them too little that will be of real value beyond a credential that may help them find a job” (Interview 1/ September 19). Ron claimed a student might graduate from college and find a satisfactory job, but that would be useless if he or she had not been taught how to think. However, Ron recognized that the burden of educating students was not entirely on the university; students must also contribute to their own education. He claimed

students often lack the motivation, focus, and seriousness of purpose necessary for productive education, and he had observed that such students often graduate “without knowing how to think logically, write clearly, or speak coherently” (Interview 1/ September 19). According to Ron, learning mathematics and developing good critical thinking skills might actually “help [students] learn ways to process facts and information that they can then use to evaluate, analyze, and synthesize solutions to problems” (Interview 1/ September 19).

In analyzing the difficulties students face, Ron believed that the single greatest obstacle to learning mathematics was a student’s reading deficiencies, particularly where symbols and abstractions were concerned. He clarified that by “reading deficiencies,” he did not mean their lack of ability to “pronounce words or associate names and symbols but rather their inability to comprehend the material” (Interview 2/ October 23). For example, in his calculus classes, much of many students’ difficulty arose from their not knowing how to translate a word problem into an appropriate equation.

Ron claimed that progressive knowledge development was the key to long-term progress in mathematics because everything that one learns is merely a foundation for the next level. Ron related learning mathematics to building a house. Learning mathematics requires a solid grasp of a large amount of basic knowledge and techniques, just as a solid foundation is required for the structural integrity of a house to remain intact. There are no concepts in mathematics that can exist without a foundation, just as all houses need solid foundations. Ron stated that students should master the fundamental skills and establish a knowledge base. Thus, every instructor’s focus should be on teaching mathematics fundamentals. He believed that the reason many students do not understand fundamental concepts, such as why the fundamental theorem of calculus is true, is that “they have not grasped what an abstractly defined function is, or what



derivative truly means” (Interview 2/ October 23). In Ron’s opinion, students needed to take time to build a solid foundation of basic skills and concepts, constantly refining and adding to this base, so they could expand their knowledge. Having such a solid foundation in the basic concepts makes subsequent progress possible. Therefore, Ron noted that a failure to develop a proper understanding of fundamental concepts or skills would prevent the student from improving his or her mathematical knowledge:

It is impossible to succeed in mathematics if you don’t know what a function is or how to solve basic equations. You need to learn some basic “tricks of the trade” and how to use them in a very simple context. (Interview 2/ October 23)

Lynn and Ron both saw that the value of learning mathematics was not about learning a bunch of facts but about training the mind to think. They perceived that their main objective was to make students think by helping them strengthen their critical thinking and analytical skills, as well as expand their mathematical knowledge. They also believed that having a solid algebraic knowledge base and symbolic manipulation skills was a must for learning calculus. For successful mathematics learning, they both preferred that their students use pencil and paper so that they could put their ideas clearly on a piece of paper instead of using computing technology.

### **Lynn’s and Ron’s Conceptions of Teaching Calculus**

In her calculus classes, Lynn chose to follow a chronological order when presenting concepts rather than using the order that appeared in the textbook. According to her, “Calculus books are not written in an order that makes the most sense for [students’] learning” (Interview 1/ September 12). Lynn thought that following the order of material as presented in the books gave students the wrong impression by conveying a false history of mathematics. She reorganized the order of material in her syllabus so that she could present the information in an order that she considered more logical. To provide the historical background of calculus

concepts, Lynn taught concepts in a logical order, instead of strictly following a historical order in which concepts were developed chronologically, so that her students could understand the ideas of calculus and see how they were developed out of prior ideas. Using her own notes, Lynn claimed that she did not “spend a certain amount of time by thinking about whether a given problem or theorem was true as stated” or working through the material and trying to determine how the author’s exposition of this material dovetailed with her own conceptual framework (Interview 1/ September 12). Furthermore, she also expressed that just as “writing a research paper solidifies one’s understanding of some of the subject,” writing one’s notes would force her to think about the interdependence between problems that she might not “see merely working through or teaching out of textbook” (Interview 1/ September 12).

Through her teaching, Lynn wanted her students to view calculus as an ongoing intellectual activity and not as an end in itself. In her classes, she told her students not to become focused on getting the right answer, but to focus on learning the process. She argued that if students understood the processes, “they will understand why and when certain mathematical algorithms are implemented (Interview 1/ September 12). According to Lynn, a primary goal of teaching calculus was to enable the students to understand the foundational features that lie at the heart of calculus: “Students need to understand rates of change [related rates] to see that the world is not linear” (Interview 1/ September 12). With the development of such an understanding, students could start to see calculus as a fascinating intellectual adventure that allows them to see the world differently. Furthermore, seeing that the concepts of calculus had been some of the most influential ones throughout human history, students could finally start appreciating why the concepts of calculus had been so powerful in their applications.

Lynn conceived of teaching as the transmission of knowledge and tried to address the issue of the students' understanding and use of the material. As the instructor, she recognized the importance of structuring the information and organizing her teaching to make it easier for students to understand or remember the knowledge and skills. She perceived good calculus instruction to include delivering the lecture, presenting relevant ideas and theories, conceptualizing as precisely as possible, and using concrete examples. She elaborated: "It is important to give more concrete and updated examples. When you give examples, you can capture their attention and make it easier for them to remember" (Interview 2/ October 28).

In her calculus classes, lecturing was the main instructional method that Lynn implemented. Lynn always started her teaching with a brief synopsis of the material covered in the previous session because she did not want to slow down the lecture. She explained that "at the start I refer to the synopsis, and I show what we've done" (Interview 2/ October 28). She then typically used her lectures to demonstrate calculus concepts, to present derivations of mathematics theorems, and to show examples of how concepts could be used to solve problems. She believed that good lecture demonstrations of applications of calculus concepts and ideas were "absolutely indispensable as tools for helping students to relate calculus to the real world" (Interview 2/ October 28). Lynn thought the least effective way of using lecture time was to present the solutions to the traditional drill type of calculus exercises. Although Lynn acknowledged that it could be useful to first watch an expert exercise some mathematical skills, she argued that those skills still had to be learned through repeated practice; simply watching an expert was not "the most important part of the learning mathematics process. If it were, the millions who watch professional sports would themselves naturally develop into top-notch players" (Interview 2/ October 28).

Just because Lynn emphasized that students must practice mathematics a lot on their own to develop their skills did not mean she believed that the role of the instructor was in any way diminished. On the contrary, she believed that instructors could have enormous effects on students through their teaching: “You really can. ... Well, in that sense of stimulating a desire to find answers” (Interview 2/ October 28). She thought that she had significant control over how much her students would learn. As the instructor, she would present the calculus concepts and draw links between them and other parts of mathematics. She perceived it as her duty to motivate her students by “opening the door, saying, ‘Here’s something you didn’t know, and it’s worthwhile knowing, and you can find out’” (Interview 2/ October 28). However, Lynn clearly saw the learning of the material as nonproblematic. If material was “presented properly, so long as students paid attention, they would learn” (Interview 2/ October 28). Regarding the students’ role in learning mathematics during lectures, Lynn asserted, “They’ve just got to sit there and pay attention” (Interview 2/ October 28).

In explaining her approach to curriculum and subsequent assessments, Lynn stated that she was proud of setting high standards by developing challenging assignments and then grading them rigorously. She believed her students learned more when they wrestled with the material, which she claimed happened when she provided fundamental ideas, rather than just formulaic approaches that were easily learned and just as easily forgotten. Lynn asserted that the best evidence that her strategy worked came from the dozens of students who returned after taking one or more advanced courses to tell her that they could “now appreciate just how much they had learned in [my] class” (Interview 2/ October 28).

In addition to an insistence on a difficult curriculum, Lynn also insisted that her instruction not rely on any computing technology. She did not believe there was any way that

computing technology could be used to enhance her teaching or help to deliver knowledge to her students. She opposed efforts to push the integration of computing technology into calculus classes, remarking, “There is probably a great place in education for hammers and shovels, too, but the calculus class isn’t it” (Interview 2/ October 28). Lynn believed her responsibility was to teach her students how to think through a problem, and she could not see any value in providing shortcuts by using computing technology. Her classroom policy forbade the use of calculators on any test in her courses. Lynn allowed students to use calculators in class only to work on problems that she considered to be very complicated and difficult. Although she thought that it would be helpful to create graphs by using computing technology, she chose not to do so because she thought it just took up class time when she could “easily draw a graph very quickly by hand” (Interview 2/ October 28).

Lynn called the use of computing technology nothing but a “showcase” of teaching calculus; she claimed that the technology could provide some intriguing and entertaining tricks, but lacked real substance. Although the use of technology might attract students’ attention, Lynn believed it could also derail the instructor’s efforts to help students learn the actual concepts. When asked which animal she would choose to describe the technology, Lynn chose an elephant. She thought technology, like an elephant, can be very helpful for some tasks, but it also has the potential to be very destructive: “I like to look at elephants; everyone likes elephants because they are cute. They are really neat, and they can do a lot of stuff. But they are really just slow moving creatures” (Interview 2/ October 28). Lynn explained that elephants, like computing technology, may be beneficial for difficult tasks but not for simpler ones. For example, an elephant may be useful for moving large, heavy objects; however, it would be an inefficient use of time and energy to hoist a lightweight item onto an elephant’s back in order to transport it. A

person could complete this task much more easily on his or her own. Similarly, computing technology may be useful for advanced level mathematical investigations; however, Lynn explained that students could solve simpler problems (such as those they encounter in calculus courses) more quickly and efficiently without the encumbrance of computing technology, which only serves to make the task unnecessarily complicated, thereby slowing down the students' progress.

For Ron, the primary function of his calculus class was to provide experiences or exposure to thinking through abstract and technical material, which students found challenging because of the inherent abstraction and precision. Lamenting that so many students take calculus classes without possessing the necessary basic mathematical knowledge, Ron believed that students should not be allowed to take calculus until they had a good understanding of functions, as demonstrated by a clear grasp of algebra. If a student could not demonstrate a satisfactory level of algebraic fluency, Ron believed that the student was not ready for calculus and would likely fail his course. Complaining about the current trend of de-emphasizing mathematical proofs, Ron suggested that such trends diminish the rigor of calculus classes. As an example, he noted:

Current reform movements have taken all of the brilliant ideas out; for example, what does it mean to have a limit? That's an idea you never hear about anymore. We've taken those ideas out because the people coming in don't have the background for it. (Interview 1/ September 19)

Personally, Ron enjoyed solving equations and understanding how mathematical theories work in a problem-solving context. Based on his classroom experiences, Ron thought that students who were engaged in a variety of problem-solving activities tended to retain more information than those who received only lecture-based instruction. Accordingly, one of Ron's main goals as an instructor was to help his students discover how to apply general problem-

solving strategies to a rich variety of problems. In all of his classes, Ron emphasized problem-solving skills as the way to develop conceptual knowledge. He thought the investigation of practical problems should lead to formal definitions and procedures, instead of the other way around. Ron's experiences had shown him that students who focus solely on mathematical theorems and proofs often fail to understand how, why, or when to apply their knowledge. Ron observed, "Sadly, students too often believe that passing exams defines mathematical learning, but they really do not understand most of the mathematics they are doing or why they are doing what they are doing" (Interview 2/ October 23). He believed that students graduate from high school without developing the necessary skills for solving problems. Ron claimed the goal for most students in high school was not to learn mathematics through understanding the problem but to get an answer that agreed with the one in the back of the book. As a result, students learned to do computations but never understood why a particular algorithm worked. In reflecting upon the prevailing attitudes among students towards mathematics, Ron said:

[Doing computations] is almost irrelevant, as computers can do this. Students need to know mathematics, and not just do calculations. In my classes, only a few students actually know how to solve problems; the rest of them are sitting and waiting. They are waiting for the problem to be solved by somebody other than themselves, or they are waiting for me to tell them how to solve it. They show no initiative and are totally unfamiliar with problem solving. (Interview 2/ October 23)

Ron typically gave his students some simple problems at the beginning of class and then followed up with more complicated problems. If his students had difficulty with complicated problems, Ron tried to break the problems into smaller parts because he believed that strategy helped the students see where to go with the problem. Ron noted, "Sometimes [my students] look at a complicated problem and have no idea where to start. They just don't know how to apply what they know" (Interview 2/ October 23). In his classes, Ron told his students that arriving at a wrong answer is not necessarily a bad thing; it can lead to gaining a better

understanding of the concepts of the problem solving process, which is a lesson of the utmost importance. Ron encouraged his students to work together to solve problems because “through collaboration, students learn that others’ mistakes may actually be helpful in figuring out the problem as a whole. They discover that using and combining the techniques and ideas of others can help to simplify the problem-solving process” (Interview 2/ October 23). Ron had seen that when students compared and contrasted their solutions with those of their peers, they could learn to explain how they arrived at their answers. Ron noted that when students learned how to verbalize their reasoning process, “they are actually learning more than if I just told them that their answer was correct” (Interview 2/ October 23).

Ron also emphasized the need for students to develop a better sense of whether an answer that they generate is reasonable. In order to know if a conclusion is reasonable, Ron thought it was imperative that students understand enough of the conceptual underpinnings of the mathematical model to be confident in its predictions over the full range of conditions under which the process is applied. Ron compared the problem-solving process to swimming: “It is important to work problems through and then check your answers, just like it is important to practice swimming in shallow water before diving into the deep end” (Interview 2/ October 23). Ron saw the presenting of material to students or students’ completion of assigned problems as being the same as the students learning the material. If the material was presented clearly to students, then they would learn the material. He saw mathematics as intrinsically interesting and believed that the concepts of calculus, which he claimed had intrinsic interest for students, would motivate students to keep up with the rest of the course. Overall, Ron demonstrated a teacher-focused information transmission model of teaching; he seemed to focus on how the students



appeared to respond to the teaching and the material, rather than what they might have learned or not learned. After teaching the related rate concepts, Ron stated:

I was pretty sure they were all with me through it, and that's why I sort of went over things. I know they were sort of concentrating and that they were paying attention. They were nodding heads, so I knew that they were concentrating, and they were paying attention. (Interview 2/ October 23)

In his calculus classes, as a policy, Ron encouraged students to use calculators on homework problems, but not during tests. He did not allow students to use calculators during exams, because he believed some questions would be much easier with their use, and he was not testing his students' abilities to find the answers by using computational technology. Letting his students use computing technology during a test would have prevented Ron from seeing "how [students] are thinking about the problem, as well as gauging their mathematical understanding" (Interview 2/ October 23). When Ron was asked what animal he would choose to describe technology, his response was a work horse. Just as a work horse is useful for completing heavy and mundane work, so, too, computing technology, in Ron's opinion, is useful for carrying out the laborious calculations necessary to solve complex mathematical problems.

Although Ron found computing technology extremely useful for doing mathematical research, he still preferred to perform mathematical calculations by hand rather than with a computer or calculator. Ron could not foresee himself integrating technology in any meaningful way into his calculus classes: "I don't see [validity in] the argument that it can be used, or that it is an advantage for first and second semester calculus students" (Interview 1/ September 19). Although he was convinced that computing technology can be used to provide help with visualization in upper level classes, such as to demonstrate certain graphs or vector spaces, Ron could not envision using the same technology in regular calculus classes. When asked what it would take for him to integrate computing technology into his calculus classes, Ron's response

was “I guess it would take a lobotomy. I just can’t imagine doing it” (Interview 1/ September 19).

Ron perceived mathematics as work best performed with paper and pencil. He believed the main role computing technology can play is to help students visualize the mathematical properties under consideration. He did not, however, think the use of computing technology was necessary for creating a successful visual representation: “I don’t see why it is any better than what I can draw on the chalkboard” (Interview 1/ September 19). Ron believed that some instructors might choose to use computing technology if they have a hard time in getting a point across because having a visual component, such as graphs and pictures, can help to demonstrate certain principles. Ron said that he, however, did not have any difficulty in making visual components clear to students; therefore, he did not believe that computing technology would add any value to his teaching or to students’ learning, and he did not think it would be useful in his calculus teaching. He could, however, imagine that computing technology had the potential to be useful, but it was not necessary to make the technology an integral part of calculus classes. Ron wanted to see examples of successful implementations of technology integration before he would be convinced that it would be beneficial to integrate them into his calculus classes: “If I can somehow see how it would help [students] if we did use some technology in the classroom, then I probably would use it. But right now, I just can’t see it. I would need to see how they do it first” (Interview 2/ October 23).

Ron viewed technology as a tool and a resource, like a dictionary. He believed it should not be the main feature in mathematics instruction, but rather a supporting tool, at most: “I am not against it in any real way, but I don’t use it, purely because I don’t think it is useful for what I have been doing” (Interview 2/ October 23). As a resource and a tool, Ron argued, computing

technology can be used to make students' work easier, but not to replace the need for developing one's own basic knowledge in learning calculus. According to Ron, the main problem is not the utilization of technology per se, but how it is used by students and instructors. He thought that instructors need to examine the purpose of the lesson—that is, the nature of students' current needs—and how the technology fits with that purpose. In upper-level mathematics classes with mathematically mature students, if the activities are well designed and used, the use of computing technology can increase the variety of problems that students can work with and ultimately solve. Ron did agree that the university mathematics curriculum should investigate taking advantage of computing technology to assist students in gaining mathematical understanding. Ron believed that gaining a solid mathematical foundation helps students to become powerful and thoughtful thinkers, communicators, and problem solvers. In mathematics instruction, however, Ron maintained his belief that the use of computing technology should not be an instructor's primary focus in teaching calculus.

Lynn and Ron both held this conception of teaching as a teacher-centered activity. Its main aim was to transmit knowledge to the students, who were considered passive recipients of information. Lynn's and Ron's calculus teaching was content centered, and their attentions were directed more towards the class as a whole, although that did not imply there was no recognition of individual differences. They tended to put more emphasis on the need to ensure that all students met the same externally imposed standard, rather than to tailor their teaching to suit the different needs of the individual students. In their calculus classes, the students' roles were reactive; that was, they were asked to internalize patterns of thought explained to them by the instructor and then to make those thought patterns a part of their own intellectual repertoires.

## **Lynn's and Ron's Experiences of Teaching Calculus**

Lynn and Ron both saw learning mathematics, especially calculus, not as a process of learning how to get an answer, but rather one of learning how to think. They believed that students should be able to understand what they are doing and be able to solve calculus problems without the use of technology. Recalling previous calculus teaching episodes, they were categorically opposed to the use of computing technology in their calculus classes based on their belief that a heavy reliance on technology would prevent their students from actually thinking through the problems. In Lynn's opinion, "The iPod generation of today wants to be spoon-fed with little of their own effort. They think all answers are accessible at the push of a button" (Interview 1/ September 12). Ron expressed the same idea: "Unfortunately, there are a lot of students becoming totally dependent on technology to do mathematics" (Interview 1/ September 19).

Lynn's calculus teaching style came from her own mathematical experiences. When she was a student, she had focused more on doing mathematical proofs and providing reasons behind concepts than on showing the applications of calculus concepts. Through her calculus teaching over the years, Lynn saw that the use of computing technology served as an obstacle to helping students learn basic mathematical skills and concepts. She recalled several instances when she had observed students who wanted or expected to be able to use their calculators for basic arithmetic calculations and mathematical operations. Witnessing those experiences continuously in her calculus classes made her believe that such early and heavy dependence on calculators prevented the students from developing a clear conceptual understanding of calculus concepts. Furthermore, those experiences convinced Lynn that a student could not be successful in calculus classes without a good foundation in algebra. She offered an example of students who had an

algebraic knowledge gap to demonstrate how computing technology could serve as an impediment for students' calculus learning:

Ask students to calculate  $8^{-2/3}$  [and] you will see many students write [using their calculators] 0.0552, and some will write 0.25, instead of  $1/4$ . The first answer demonstrates students don't know how to use their calculators, but I am not happy with the answer 0.25 either. Although calculating such a power is quite easy for many, the procedure reflects considerable mathematical knowledge gap for those students who just punching keys to get the answer. You see that these students have difficulties in understanding negative and rational exponents and the rules of exponents. (Interview 2/ October 28)

Lynn also thought computing technology got in the way of teaching calculus, and not just learning. She insisted that when students become dependent upon computing technology, they resisted developing a proper understanding of the underlying concepts. Lynn observed that especially the use of graphing calculators became a distraction and made students resistant to learning even fundamental concepts, such as the transformation of functions and the unit circle: "In one class, when I asked students if they knew how to graph  $1/x$ , most of them answered yes. But when asked who knew the properties of the function, none of them could come up with an answer" (Interview 2/ October 28).

Lynn thought that students should not have accepted computing technology as an authority, but rather as a medium to engage with as they were developing their understanding of mathematical procedures, structures, and relationships. She thought students ought to understand what they were doing rather than blindly trusting a machine to provide the correct answer. Lynn further explained that simply getting a correct answer did not also mean the method was correct or that the answer was always the best one. She wanted her students to understand the importance of developing a level of mathematical competency to decide whether the computing technology had provided a reasonable answer. Because computing technology might give

answers that are misleading unless analyzed intelligently, Lynn did not let her students use it in her calculus classes. She explained her reasoning:

Students can perform very complex mathematical operations with the touch of buttons, but they lose the opportunity to reflect upon the actual calculations. Students often engage in trial-and-error, guessing the answer from feedback without developing a proper mathematical understanding. I think students gain more intuitive understanding about mathematics by actually going through the process rather than just pushing buttons and getting an answer. (Interview 2/ October 28)

Similar to Lynn's experience, one of the main reasons Ron provided for not encouraging his students to use computing technology in his calculus classes was his consistent observation of its detrimental effect on the development of a student's sense of numbers. Ron was discouraged by his students' lack of ability to do basic arithmetic, which he attributed to the overuse of calculators: "My experience is that there are students who have used calculators so extensively they don't even understand basic arithmetic from grammar school" (Interview 2/ October 23). He said that early introduction and overuse of calculators prevented some students' development of a sense of numbers. He claimed to have students who "did not know what the square root of 16 is," and he declared, "I am old enough and conservative enough to think this is scandalous" (Interview 2/ October 23). Ron witnessed many of his students' lack of ability to do basic arithmetic, which he considered an unquestionable mathematical skill that they should have mastered before they started to learn calculus. He claimed to have several students in his calculus class who could not do problems that involved multiplying two digit numbers: "The students had to multiply 13 by 65, but I didn't allow them to use a calculator. So this one student wrote the number 65 thirteen times in a row and added them all up" (Interview 2/ October 23).

All these experiences convinced Ron that the availability of calculators made students lose their number sense. He claimed that undergraduate students do not have a sense of or a desire for doing arithmetic in their heads because of the overuse of calculators. He contended

that an inappropriate use of calculators might also interfere with the students' ability to understand the meaning of fractions and to compute with fractions. Ron found that students are especially losing their capability to notice detail, which is a skill required to understand concepts in algebra. He observed:

It is hard to learn factorization if you have no number sense. If you don't have a calculator, it is a lot easier to multiply two numbers by breaking them up into intelligent parts. I think if we do more mental math and more mathematics without a calculator, we can develop a better sense of the distributive property and all the different parts you can break a number down into. (Interview 2/ October 23)

One of the reasons Ron was reluctant to invest his time in learning how to integrate computing technology into his calculus classes was that he believed that the integration of computing technology was not emphasized in his department. There was no incentive structure in place to encourage technology integration efforts, and there was no clearly articulated vision for how technology could be effectively integrated into mathematics courses. According to Ron, the attempts to integrate technology into mathematics courses were in actuality attempts to put a good face on the department, but without true conviction behind the efforts. Ron explained, "It is required for a mathematics department to appear more modern or forward thinking in the eyes of the university. It is not necessarily clear [throughout the department] that this is a good thing" (Interview 2/ October 23). Ron claimed that when he examined the gap between the promises of technology in calculus teaching and learning and the reality, what he found was "a lot of wishful thinking." In theory, he could see that computing technology had the potential to be used to produce better calculus instructional practices, but his own experiences with students in the classroom had demonstrated the opposite effect.

Through their previous calculus teaching initiatives, Lynn and Ron both became convinced that when students became dependent on a graphing calculator, they did not develop a

proper understanding of the underlying concepts of calculus. These professors' previous negative experiences of teaching and learning calculus with computing technology had convinced them that especially the use of graphing calculators became a distraction and made students resistant to learning fundamental concepts of calculus such as the limit and maximum and minimum problems. They observed that students tended to blindly accept computing technology as an authority rather than as a medium to engage with as they develop an understanding of mathematical procedures, structures, and relationships. They wanted their students to understand what they were doing, rather than blindly trusting a machine to provide the correct answer. They also wanted their students to understand the importance of having a level of mathematical ability sufficient to decide whether the technology had provided a reasonable answer.



## **CHAPTER 6: TEACHING CALCULUS AFTER ONCE USING COMPUTING TECHNOLOGY**

### **Ken's and Janet's Conceptions of Mathematics and Learning Mathematics**

Ken had 8 years of experience teaching college-level mathematics and had received a teaching award from his previous institution. He took pleasure in mathematical research, and he described moments of excitement he had experienced when he was engaged in it. Ken eagerly explained the thrilling sensation a mathematician got from doing mathematical research by seeing farther, as when he has been “struggling with a lack of understanding,” but all of sudden, he “finds the right way to think about a problem” (Interview 1/ September 18).

Ken liked mathematics as a subject because it was very logical, and he stated, “Math is about thinking clearly and precisely. I think there is something wrong with society to think that is a bad thing” (Interview 1/ September 18). For Ken, learning mathematics was not about memorizing facts, but a process of learning how to think. He believed that mathematics is not “what ends up on the board; mathematics is what happens in our head” (Interview 1/ September 18). For Ken, the primary function of learning mathematics was to provide experiences or exposure to thinking through abstract and technical material. Lamenting that so many students were taking his calculus classes without possessing the necessary basic mathematical knowledge, Ken believed that the students should not have been allowed to take calculus until they had an extensive understanding of functions, as demonstrated by a clear grasp of algebra. If a student had not demonstrated a satisfactory ability to perform algebra fluently, Ken believed that the student was not ready for learning calculus and would likely fail in his course.

In Ken's opinion, mathematics is a hierarchical subject that builds upon what the student has already learned. If a student was still struggling with basic concepts, that knowledge gap would prevent the student from being able to fully grasp calculus concepts. Ken claimed that developing a successful mastery of calculus was dependent upon first gaining a solid understanding of algebra. He noted that true algebraic competence includes not just learning "the rules for algebraic manipulations but also understanding the logical reasons that underlie those rules" (Interview 1/ September 18). He stated that the development of competence in algebra required that students be able to draw on their previous mathematical experiences in order to monitor their own progress and figure out the appropriate next step in a problem.

Ken defined *learning mathematics* as his students achieving an acceptable level of mathematical competency. His definition of *mathematical competency* included the abilities to devise mathematical arguments to justify mathematical claims, to follow and analyze others' justifications of claims, "to understand what mathematical proofs and conjectures are and how they differ from other kinds of mathematical reasoning," and to handle the scope and limitations of given concepts (Interview 1/ September 18). Ken stated that he viewed learning as involving basic transmission of information; however, my classroom observations indicated that he frequently engaged students in the lecture. He did not simply assume that what he said was absorbed; he continued to ask students questions throughout the lecture in order to make sure that they comprehended the lesson. For meaningful mathematics learning, Ken believed that placing an emphasis on grasping the meaning behind the concepts and allowing time for self-discovery was important. During his class lectures, he stated that he tried to facilitate students' understanding by using a Socratic method to guide the conversation: "In my experience, if

students are simply given an answer, they are not forced to go through any thought processes to figure out the problem” (Interview 2/ October 23).

Ken also expressed a personal belief in the beauty of mathematics, and he enjoyed sharing a subject in which he found beauty. He also mentioned the challenging aspect of mathematics as a discipline; in fact, the challenge he found in mathematics had always appealed most to him. In addition to enjoying conversations with people about mathematics, he viewed teaching mathematics as “a pathway to meaningful discussions” (Interview 2/ October 23). Ken described learning mathematics as like learning to dance or play an instrument: “It takes so much practice to get the feeling of certain movements into one’s fingers or legs” (Interview 2/ October 23). According to him, learning mathematics required a great deal of practice to attain a level of mastery over mathematical concepts; therefore, memorization was a necessary evil. For Ken:

It [doing mathematics] requires a lot of practice. I mean, it is not like they [students] should be sitting comfortably there and just watching me do it—like sort of attending a concert when somebody plays piano and thinking that they are going to learn by just watching somebody. I want them to get their hands dirty and, you know, learn the concept. I want them to do a lot of problems. (Interview 2/ October 23)

According to Ken, mathematics learning consisted primarily of two components: the formal symbol manipulation, which was relatively straightforward and routine, and the more complex mathematical modeling. In Ken’s conception, mathematics was a symbolic language as well as a tool one used in order to think and analyze. The importance of symbolic fluency hinged upon symbols’ roles as simplifiers; they allowed people to express certain ideas briefly, accurately, and eloquently. Thus, the development of symbolic fluency was necessary for understanding abstract mathematical structures, concepts, and patterns. Ken described symbolic language as a medium to create mathematics and symbols, as well as a necessary tool to express mathematical thinking. Ken believed that symbolic language is “like using notes to record music

in your head. You can use different notes to create different musical tunes. Once you understand the rules, you can start being creative and expressing yourself” (Interview 2/ October 23).

Regarding the use of computing technology in mathematics, Ken was concerned about possible interference with learning because he thought that his students lacked the maturity to use the technology in a way that would further their mathematical understanding. He thought the use of computing technology prevented some students from developing logical thinking skills, which he contended should be the primary purpose of learning calculus. Ken said that the use of computing technology, especially the calculator, gave “students a false sense of confidence about their mathematical ability.” He expressed the concern that students spent far too much time trying to learn how to use the calculator, “instead of learning how to do the mathematics” (Interview 2/ October 23). Consequently, they focused on learning technology skills, but not necessarily on how to think logically when organizing and processing information. Although Ken did admit that a graphing calculator could potentially provide motivation and assistance, its positive effects would likely be overshadowed by the inappropriate dependence on computing technology that students developed: “If a student can’t multiply a number by ten or by negative one without whipping out his calculator, he is demonstrating an unfortunate lack of number sense. The calculator is hindering the learning process instead of helping it” (Interview 2/ October 23).

Like Ken, Janet also emphasized the ways that learning calculus could positively affect students’ logical reasoning abilities. Janet had earned an M.Ed. in mathematics education, and her undergraduate degree was in business. She was an assistant professor of mathematics at Fairway College at the time of the study. She had taught 2 years at a high school prior to teaching at Fairway and had 6 years of experience teaching college-level mathematics. Janet

believed that the number of undergraduates she had taught provided her with a certain perspective on teaching mathematics as well as a wisdom that she was willing to pass on to students. She also thought that calculus concepts could change the way students think without the students even realizing it. She stated that calculus was everywhere: “It is a significant achievement of human thinking that should be enjoyed and appreciated by all students” (Interview 1/ September 5).

Janet perceived calculus as a powerful tool that provided many different ways of thinking and looking at problems. She knew there was a difference between the kinds of problems that someone at the precalculus level could work on, as opposed to someone who had studied calculus. She believed that without calculus, people would be attempting to solve problems without the fundamental tools and unique thought processes that come from learning the subject. According to Janet, most students who had taken her calculus class would not directly use calculus in their day-to-day lives, but all of her students should use some basic concepts and thinking skills that were shaped by calculus. For instance, the ability to think in more continuous terms rather than in discrete terms can help people deal with life changes: “Calculus describes and deals with motion and allows us to view even static objects in a dynamic way.” (Interview 1/ September 5)

Janet saw mathematics as paper-and-pencil work. For learning mathematics, Janet stated that the development of basic skills was a must. Without mastering the fundamental building blocks of mathematics concepts (e.g., finding the derivatives of certain functions), students cannot move on to the complex mathematical concepts and their applications. She expressed that concept by comparing the process of learning mathematics to building a house: “You need a solid foundation to start with. As an instructor, I am eager to build a solid foundation, and then to

move on. Without that solid foundation, students are left building houses of cards” (Interview 1/ September 5). Janet believed it was her job to help students develop a strong foundation through logically structured lectures, and her interview transcripts contained several references to frequent quizzes and tests to make sure that the students had learned the material: “I give [the students] a lot of assignments, and a lot of quizzes to force them to study. Basically this is the only way that I think will work” (Interview 1/ September 5). Without such constant assessment, Janet claimed that students would not study or learn the material and would, therefore, not have the solid foundation of knowledge necessary for learning future material.

Janet’s conception of seeing mathematics as paper-and-pencil work shaped her vision of computing technology’s integration into calculus classes. She saw the use of technology as a more advanced skill, and she claimed that most students in calculus classes did not possess the mathematical maturity or the knowledge base required to handle learning mathematics in conjunction with technology. She observed, “I want to work on how we learn the old-fashioned way. Learning with technology is a more advanced skill. We have to have some foundation before we add in technology” (Interview 2/ October 16). Janet thought that there was a great deal of difference between knowing something and understanding it. She argued that the use of computing technology could deceive some students into believing that they “know a lot about mathematical concepts, even though, they actually do not understand or possess the required skills to even approach the concepts” (Interview 2/ October 16). Without achieving a certain degree of competence in basic skills, Janet argued, her students would not be able to handle more advanced mathematics. As she put it, “There are basic skills I want them to have, and they need more practice with them” (Interview 2/ October 16). In her opinion, trying to learn mathematics without doing it by hand first was putting the cart before the horse.

According to Janet, power gained with the use of technology required control, and if students had not mastered the necessary mathematical concepts, it was not helpful to give them new tools that they were not capable of mastering. She claimed that if “students do not know enough algebra to solve a certain problem, then they will lack the fluency or experience to use computing technology effectively and confidently in problem solving” (Interview 2/ October 16). Janet believed that using computing technology before mastering basic skills only hindered students’ skill development and mathematical understanding. She did not, however, object to the use of computing technology once students had learned the concepts and developed the requisite skills. For example, she did not object to a Calculus II student finding the derivative of a function by using a TI-89 calculator; however, she opposed the use of the same device by the same student doing integration. She explained,

I am uncertain about introducing a calculator to multiply numbers for the first time. I want students to be able to multiply numbers by hand, but at the same time, I don’t want students always to do it by hand. (Interview 2/ October 16)

When introducing a mathematical concept for the first time, Janet maintained that a technology-free approach was best for students’ learning.

The learning outcome Ken and Janet sought, as a matter of traditional expectation, was students’ knowledge of the curriculum material as demonstrated by their answers to questions in both informal and formal settings. They acknowledged that students may have had problems understanding the material, and they saw the clarification and illustration of textbook material as a key part of their role. By explaining the ways in which textbooks represented and structured established knowledge, they believed they helped their students to understand the knowledge as it was presented. They believed that if a student were struggling with basic concepts, that knowledge gap would prevent the student from being able to fully grasp calculus concepts.

Furthermore, both Janet and Ken held the belief that many of their students lacked the ability or motivation to grapple with difficult mathematical concepts and, in general, lacked the will to succeed.

### **Ken's and Janet's Conceptions of Teaching Calculus**

Ken viewed teaching as a basic transmission of information, and he perceived his job as presenting concepts and ideas in a clear and comprehensible manner. For him, students needed to show an interest in learning mathematics, and the rigorous nature of calculus classes should not be compromised. Because Ken found mathematics intrinsically challenging and beautiful, he perceived his job as showing and sharing that beauty with students by “helping them move forward when they stumble on a roadblock as they learn” (Interview 2/ October 23).

Although Ken stated that he saw teaching mathematics as transmission, he frequently engaged students in the lecture to ensure that they were appropriately involved. Ken did not simply assume that what he taught was absorbed; he continued to ask students questions throughout the lecture in order to make sure that they comprehended the lesson. Ken believed that placing an emphasis on grasping the meaning behind the calculus concepts and allowing time for self-discovery was important. However, he noted that attempting to carry that out in the classroom was an inefficient use of classroom time because it took away from the time needed to cover all the material on the syllabus. In his calculus teaching, his main emphasis was on covering the whole syllabus and meeting the examination requirement. This conception could be illustrated clearly by the following comment of his perceived responsibility as an instructor:

You should teach [the students] what they should know about calculus. I will cover the syllabus fully. I will not skip any part of it, and I will not teach only the materials that will be examined. I always teach them all the topics included in the syllabus. (Interview 2/ October 23)



According to Ken, one of his main responsibilities as a mathematics instructor was to broaden students' understanding of mathematics by developing their problem-solving skills. Therefore, Ken believed that by working on challenging mathematics problems, students could learn how to approach problems in ways they might otherwise never have considered. Consequently, he believed that if students learned problem-solving skills in his calculus class, they might then be able to apply similar mental strategies in other aspects of their lives. In his experience, Ken found that students in general liked to avoid thinking critically; however, he hoped that, through problem solving, mathematics could help students broaden their critical thinking and reasoning abilities. Ken said, "I think some of these students don't use their brains that much, and math, I think, kind of forces them to actually use their brains" (Interview 1/September 18).

For Ken, the primary function of his calculus class was to provide experience or exposure to thinking through abstract and technical material, which some of his students might find challenging because of the inherent abstraction and precision. He lamented that so many students were taking calculus classes without possessing the necessary basic mathematical knowledge, and he believed that students should not be allowed to take calculus until they had an extensive understanding of functions, as demonstrated by a clear grasp of algebra. If a student had not demonstrated a satisfactory ability to perform algebra fluently, his or her knowledge base and skillset was not extensive enough to properly succeed in calculus, and would probably result in a failing grade.

Ken's teaching also reflected a content-oriented approach more than a process-oriented approach. He viewed the role of instructor as a guide who attempted to present the content in a clear and logical manner by stressing underlying mathematical procedures and logical relations

among concepts. He believed that it was not good enough for his students to know only how to carry out mathematical procedures; instead, Ken believed that “students also need to understand the logic behind mathematical procedures” (Interview 2/ October 23). Although Ken also believed that part of his job was to convince students that calculus itself was worthwhile, he had never considered how to link that belief directly to lecturing in an attempt to persuade students that his lectures were worth listening to. He was very proud of not teaching in a canned presentation kind of way: “I don’t want to engage in endless hand-holding or walking students step-by-step through by saying, ‘These are the three things to know—here, learn them ... boom, boom, boom’” (Interview 1/ September 18). Building on that strategy, Ken tried to encourage students to think creatively. As an instructor, he attempted to enhance students’ conceptual and practical understanding of mathematics through integration of concepts.

Part of Ken’s teaching involved presenting the material in a logical manner. According to Ken, progressive knowledge development was the key to long-term progress in mathematics because everything that one learns becomes a foundation for the next level. He believed his responsibilities as a teacher were to show his students what they needed to learn and to then ensure that they accumulated the required knowledge. He clarified by stating that “if a student does not understand something, he or she can simply ask,” and he would “find another way to explain it to them” (Interview 2/ October 23). Ken thought a good teacher should dominate the classroom and its elements, and the most important ways he could be a good teacher were to prepare lesson plans for efficient use of class time, prescribe course objectives, and disseminate information clearly and effectively. His goals for his students were that they learn the material quickly, remember it well, and reproduce it on demand.

Beyond simply teaching calculus, Ken also wanted to make a difference in the lives of his students, and he was committed to being a good role model for the undergraduates. Although Ken described his courses' subject content as really important, he also believed that his teaching could help students learn about life and prepare them for decisions they would have to make in the future. Ken claimed to derive great pleasure and joy from helping struggling students if he saw that they were sincerely trying to learn. He attributed the high failure rates in his calculus courses, however, to the challenging nature of mathematics as a subject, combined with the students' avoidance of seeking deep intellectual challenges. Ken stated, "My responsibility is not to babysit my students and not to make them feel comfortable with the concepts and everything. My responsibility is to get them interested enough to come to class and to do the work that they are supposed to be doing" (Interview 1/ September 18).

In addition to promoting students' interest in calculus, Ken also thought that his instruction should help them develop "mathematical competency" (Interview 1/ September 18). For Ken, *mathematical competency* implied developing proficiency at detecting, recognizing, and utilizing mathematical structures, and then drawing useful connections among different structures. Ken complained about the decrease in the rigor of calculus books and the removal of certain concepts like Kepler's Laws over the years. He also complained about the current trends of de-emphasizing doing mathematical proofs and emphasizing the use of computing technology, and he believed such trends diminished the rigor of calculus classes. He claimed that the publishers had simplified the language of calculus books to remove the vigor of calculus ideas: "They [the book publishers] took big words out because today's students don't know how to pronounce three-syllable words: 'OK, we won't say rectilinear motion; we will say motion along a line.' All calculus books are like that" (Interview 1/ September 18).

In discussing the changing atmosphere of the calculus class, Ken explained that he had used computing technology in the past but had since decided not to use it in his calculus classes. He explained that he was comfortable with using a traditional lecturing method, and the additional issues presented by the integration of computing technology were not welcome changes in his classes. He did not have a clear idea of how he might actually use computing technology to better teach calculus to his students. He acknowledged that computing technology could be a valuable tool to build students' conceptual understanding, but only if it were used appropriately. For example, Ken thought that computing technology could be used effectively in upper level mathematics classes or with high-level students who were expected to have the ability to analyze problems, apply mathematical tools to establish mathematical models, and use calculus to solve the problems. In a regular survey-level calculus class, however, where Ken perceived the goal to be learning how to learn, he did not want the technology getting in the way. According to Ken, the aims of teaching a basic survey level calculus course were that "students should gain a basic knowledge of the concepts and theories of calculus, understand the idea of analysis, develop skill in corresponding computations, and learn to work independently" (Interview 2/ October 23).

Regarding mathematics instruction, Janet expressed concerns similar to those of Ken; her main focus was to emphasize the mathematical content and the development of fundamental skills. Janet thought helping students develop strong mathematical skills and a solid knowledge base were the most important goals in teaching calculus. She believed that laying a solid foundation was very important, and that "the development of basic skills should be a part of the education of every student" (Interview 1/ September 5).

In her calculus classes, the principle of simplicity guided Janet's teaching. She believed that one of her main responsibilities as an instructor was to organize the class in such a way that her teaching would be clearly articulated and presented. In that way, Janet believed that students could easily follow her lectures. She said that one of the lessons she had learned early in her teaching career was that "it is essential that I work through all of the computations, including the ones I think are routine" (Interview 1/ September 5). Janet tried to use simple language when teaching; for example, she used the word *steepness* as opposed to *slope*. She further clarified what she meant when she said she employed simple language:

*Simple* doesn't mean dumb. *Simple* means direct and efficient without anything extraneous. I try to take away anything confusing by presenting the concept, algorithms, and ideas in a clear and logically progressive manner. (Interview 2/ October 16)

Janet believed that successful calculus instruction started with the creation of a well-thought-out lesson plan, much like an architect's starting point when building a house was to first create an architectural design of the house. Once the lesson plan is completed, "the instructor should decide what tools to use for teaching" (Interview 1/ September 5). The creation of lesson plans should come first, and the selection of instructional methods and educational tools should come second. Janet thought technology should be used if and only if it assisted students' learning and deepened their experience. Then, an instructor could choose to utilize technological investigations to solidify and further the students' already existing understanding. Janet's reasoning was predicated on the belief that "the chain of reasoning and the steps taken to solve mathematical problems and equations are important" (Interview 2/ October 16). And she thought her students would not be learning reasoning skills if she allowed them to overuse computing technology. Janet mainly regarded computing technology as only a teaching aid that helped facilitate her work and the presentation of her classroom material. She did not view her students

use of computing technology as a necessity that needed to be a fundamental part of her classroom instruction. However, she believed that computing technology could be occasionally utilized by instructors to improve teaching methods. For Janet, teaching was a form of storytelling. During our first interview, Janet described teaching as follows:

It [mathematics] is a story; I like being a story teller. When you are preparing a class or the curriculum for a whole semester, you are telling a story. I enjoy telling what I think is a good story or a beautiful story. As far as how that colors my lectures, when I create a lecture or a series of lectures, I look at it as a story. Do these parts link together and have flow like a good story? Is this a cohesive thing that makes sense? If it is just a bunch of disparate little facts, then that loses effectiveness. (Interview 1/ September 5)

In a calculus class, Janet claimed that the use of computing technology could affect only the interface of the story, or how the story was presented, but it did not materially affect one's understanding of that story. In her calculus teaching, she used technology such as PowerPoint and a SMART Board to help her make the story accessible to the students, and she claimed that those types of technology were useful in the classroom. She wanted to accelerate the pace of the class and to focus the students on understanding the information rather than on note taking. She reported that she had been eager to adopt SMART Board technology in her calculus classes because it would not require her to make any major changes in her teaching. For Janet, one advantage of using SMART Board technology to teach calculus was obvious: "The fact is that on the chalkboard, if I write a bunch of stuff and fill a board with chalk, it will eventually be erased. Then it's gone. With the SMART Board, every page is saved" (Interview 1/ September 5).

According to Janet, an instructor should not be creating lesson plans to highlight or introduce technology into the classroom. Instead, she tried to create lesson plans that highlighted the development of students' critical thinking and problem-solving skills. In other words, she believed that there must be "a convincing reason why a particular [computing] technology has to be used to meet the objectives of the lesson" (Interview 2/ October 16). Otherwise, she thought

she risked the students' learning becoming too dependent on a particular computing technology. According to Janet, when instructors teach calculus, they "should be teaching what the concepts mean, and not just how to do them with the calculator" (Interview 2/ October 16). After an initial introduction phase, however, once students had mastered a concept and the same concept was then required to reach a more complex abstract objective, Janet thought it was appropriate to use computing technology to move more quickly through the previously mastered steps. Even with that use, however, Janet cautioned that a good instructor should incorporate the technology into the calculus teaching thoughtfully: "The best thing about integrating technology is the process of blending thinking skills and hands-on skills together" (Interview 2/ October 16). She believed students should have solved a mathematical problem manually the first time in order to completely understand the details of the process. As an example, Janet described how the use of graphing calculators prevented some of her students from being able to sketch a curve by hand. She stated, "I don't like them having the calculator when they work on curves. I'm really old fashioned: I want them to be able to think through it" (Interview 2/ October 16).

Janet did not allow her students to use any computing technology on examinations or in class, because she thought her students were generally weak in their basic skills and that they lacked knowledge in algebra and trigonometry. If she were to allow her students to use calculators to circumvent the need for those basic skills, she believed the students would have had difficulty developing an acceptable level of proficiency. Without achieving a certain degree of competence in basic skills, Janet argued that her students would not be able to handle more advanced mathematics. As she put it, "There are basic skills I want them to have, and they need more practice with them" (Interview 2/ October 16). She thought graphing calculators did too much of the work for the students, and she wanted them to learn how to complete certain

mathematical processes without the assistance of calculators. When sketching curves, Janet specifically told the students to put their graphing calculators away and then asked them to do the first and second derivative tests without a technological aid. Janet thought that most students used a calculator to get away from the thinking component of doing mathematics, and that they were often confused about how to interpret the output of the calculator because they had not learned the underlying concepts. Janet's reasoning was as follows: "The technology does the crunching, but it doesn't do the thinking. I emphasize the thinking part of the process when I explain why I don't allow graphing calculators in my classroom" (Interview 2/ October 16).

Janet lamented that students' heavy reliance on calculators had caused many of them to forget how to think. Janet's policy that forbade the use of calculators allowed her to teach them how to think again. She said, "Technology does not tell students what methods they should use to solve problem; even when they use technology, students still have to be able to set the problem up themselves" (Interview 2/ October 16). In calculus courses, Janet reported that the students tended to uncritically accept the output provided by computing technology. She thought that they viewed the technology as foolproof, or as a mathematical authority, and she believed that they would internalize new concepts better if they worked on problems without using technology. Furthermore, she pointed out how the limitations of some graphing calculators might lead students to inaccurate mathematical information. For example, most graphing calculators were incapable of displaying a discontinuity adequately. Janet witnessed her students' naive acceptance of a graph and seeing the vertical asymptote as a part of the graph. Ultimately, her students' dependence on graphing calculators and their quick acceptance of graphs convinced her not to let them use calculators in her calculus class, because the calculators interfered with her teaching. She noted:



[Calculators] become a crutch. I don't like it when Calculus III students or Calculus II students are not able to graph the function  $f(x) = x^2$  without touching their calculators. And I don't let them touch calculators when this is a basic quadratic function that they need to be able to graph on their own. I want them to have a mental picture of what they want to get. (Interview 2/ October 16)

Janet did not anticipate that her students would develop new mathematical understanding by using calculators. Rather, she claimed that most of the students used them as a substitute for skills that ought to be learned, and that belief led her to view graphing calculators as potentially harmful tools. This perception controlled her attitude and behavior. For example, even though she thought it was sometimes harder for her to justify finding limit values analytically, Janet still insisted that her students learn how to find the limit of functions analytically. In her opinion, the ability to find limits analytically demonstrated students' understanding of the concept and their mathematical readiness to move to the next level. Janet later explained, "When it comes to the way I expect them to format their answers on a test, I am looking for analytical solutions. I want them to be able to know all those things" (Interview 2/ October 16).

Like Ken, Janet believed that before any technological tool was used in teaching calculus, students should have achieved the required foundational skill level and should be ready to proceed to an investigative level where the instructor could use computing technology. She perceived technology to be appropriate only as an add-on to traditional instruction; as a student-utilized tool, she believed technology had an inherently detrimental effect on students' learning. Although she also complained about her students' lack of motivation and their unwillingness to engage in difficult work, Janet did not have a strategy to address that concern; she believed that her job should entail understanding the material and then presenting it clearly. She presented the material to be learned with the intention of transferring information to the students. She believed

that there was a body of knowledge to be presented to the students, and it was her job to present it to them.

### **Ken's and Janet's Experiences of Teaching Calculus**

Ken held strong conceptions regarding the use of computing technology in teaching and learning calculus. Although he had used various types of computer software in his calculus instruction in the past, he had since decided not to use them anymore because he had observed their detrimental effect on students' algebraic readiness. In his teaching during the previous 8 years, first as a graduate student and then as a faculty member, his classroom observations led him to believe that students' difficulties with calculus reflected an underlying and even more troublesome struggle with algebra. Ken described the problems he saw in his classroom:

I can tell [that] my students don't even understand the order of operations, since they don't use parentheses correctly. They square a binomial and get two terms instead of three. Students at the university entry level are supposed to have already mastered these topics, which are included at different grades in the mathematics curriculum. (Interview 1/ September 18)

One of the main reasons for Ken's reluctance to use computing technology in his classes was rooted in his observations during his graduate school and postdoctoral study, when he witnessed many students struggling with syntax problems associated with mathematical software. He observed how the students spent a great deal of time trying to learn the syntax of the software and how to use it to understand calculus concepts. In Ken's opinion, the time a student spent learning syntax would have been better spent developing a deeper conceptual understanding of calculus. He noted,

I don't think students get out of [using computer software] what they should, because they spend so much time trying to master how to plot something, and trying to do any number of things. I think they just become a little bit frustrated. (Interview 1/ September 18)

Ken explained that his hope was to eventually see his students reaching a threshold of using computing technology in an exploratory way; he wanted to witness instances in which students were working on a mathematics problem without computing technology and then say, “Aha, Maple [a computer program] will help to explore this!” (Interview 2/ October 23). Then the students would use Maple to further explore the problem in greater detail; however, he had never seen those moments in his classes.

Furthermore, Ken also became convinced that the use of calculators blocked the development of a solid grasp of mathematical concepts. In his calculus classes, he saw that students were overusing calculators in order to avoid performing even simple calculations of integrals or derivatives. Ken would go so far as to say that the very existence of computing technology prevented the students from developing a conceptual understanding of calculus. Although his students might have refuted the claim that relying on technology was hindering their mathematical understanding, Ken did not agree:

I found out that it really didn’t help them much. I mean, they were very efficient and very good with Maple, but not with understanding of concepts. Eventually, I noticed that students were abusing technology, by which I mean they were using technology too much, and they were not really thinking. They were just punching the keys. (Interview 1/ September 18)

Ken was convinced that computing technology is far more likely to interfere with, than to promote, learning mathematics. The extensive use of computing technology could impede the acquisition of fluency in students’ basic skill development and computational procedures. Students were inclined to use technology as a crutch to avoid developing the determination and mathematical maturity needed to perform advanced mathematics. He had witnessed students going through many complicated steps with a calculator in a calculation that could have been done faster by hand. Those observations led him to conclude that there was a degree of

mathematical creativity or learning that students were giving up by using technology. Thus, in Ken's opinion, computing technology could hamper students' learning even more than it might simplify a mathematical task. Rather than trying to understand the concept, some students might choose to just use technology as a substitute. He noted that most technology, and especially calculators, serves as a hindrance in learning mathematics: "I have found it does not help and hasn't enhanced their understanding. By allowing my students to do more things with calculators, they didn't even have an understanding of what was going on. They were just punching buttons" (Interview 2/ October 23). Ken did not want to teach his students just how to punch buttons; he wanted them to learn underlying mathematical concepts, reasoning, and processes.

Although Ken stated that he enjoyed teaching, his loyalties were somewhat divided, since he would have preferred to spend more time doing mathematical research. He enjoyed doing research, and he described the thrilling sensation a mathematician may have experienced from seeing farther, as when hee has been "struggling with a lack of understanding," (Interview 1/ September 18) but all of sudden, he or she found "the right way to think about a problem" (Interview 1/ September 18). Although Ken would have preferred to devote more time to research, he understood he had to work within the climate of his university's mathematics department, which affected the division of his time between teaching and research. According to Ken, the extrinsic rewards of publication, scholarly recognition, and the current emphasis on producing research meant that instructors were less motivated to examine how their methods of instruction affected how well their students were learning calculus:

Many of us are here to do research. While teaching is important and necessary, it comes secondary to many of the professors. If a professor is going to be evaluated [primarily] on his research, where is the motivation to devote enough time to students' learning? (Interview 2 / October 23)

Although Ken could envision some potential benefits of using computing technology to teach calculus, he claimed that it was difficult to achieve that outcome for several reasons. Most importantly for him, because of current demands on his time, he thought that too much time would be required to effectively integrate technology into his teaching. Ken was in a tenure-track position at his university, and he spent much of his time and effort on his research. He believed that to focus on learning and incorporating technology into his courses would require valuable time he could be spending on research projects. Second, Ken thought that his students lacked the maturity to use the technology in a way that would further their mathematical understanding. He said that the use of computing technology, especially the calculator, “gives students a false sense of confidence about their mathematical ability” (Interview 1/ September 18).

Like Ken, Janet had tried various forms of computing technology in her calculus classes, including several varieties of software, clickers, graphing calculators, a SMART board, and Web-based tools and demonstrations, as well as online homework. In the past, she had assigned a number of Web-based tools and demonstrations to support her classroom instruction, thinking they could serve as an additional source for learning the course material, and that they would go beyond the text and classroom lectures. Janet had hoped the Web-based tools would help her students achieve a higher level of conceptual understanding, which then would have been reflected in higher examination scores. After 2 years of using the additional tools, however, Janet did not think that they had resulted in significant improvement. Therefore, she returned to using computing technology exclusively as a way to present course material in class, and her students no longer had access to Web-based tools. Janet explained,

I use technology, but what I use is different from what I expect students to use. I use technology to facilitate my story telling. I use PowerPoint slides; I use Maple to draw

figures. I use the technology to help me to draw visualizations, to present the material, to work with it. (Interview 1/ September 5)

In her calculus classes, Janet observed that if the students had been allowed to use calculators in introductory mathematics classes, they might have become dependent upon them and would be unable to comprehend the underlying concepts of the operations. She was convinced that the use of graphing calculators hindered students' skill development and learning. She provided anecdotes from various classes to demonstrate how that heavy dependence on calculators negatively affected students' learning. For example, she had observed that being able to use a symbolic graphing calculator in Calculus I classes negatively affected the student's ability to learn new material in Calculus II:

What I noticed is that students who differentiate functions using a calculator don't learn how to integrate functions, because they always use the calculator. It's like they don't really understand the concept; for them it is just punching the keys. (Interview 2/ October 16)

As another example, Janet described a time that she tried to use graphing calculators in her calculus classes to teach the concept of the limit. She hoped that using graphing calculators would save her some instructional time and would also help the students develop a fuller understanding of the limit concept. She had tried to teach the limit concept analytically, graphically, and numerically, and she found that the analytical approach to mathematics was superior to the geometrical and numerical approaches. With that perspective as her framework, Janet used the graphing calculator to show students a graphical analysis of a function so that they could see a visual image of why a limit does or does not exist. She also used the table feature in the calculator to make a table of values, so the students could see it numerically. In her instruction on indeterminate forms, Janet created table values and let the students observe patterns to estimate the limit of the function. Later, she showed her students how the same exact

value of the limit could be found by using L'Hopital's rule. When she demonstrated the rule, Janet reported that her students were quite surprised: "Of course, it [the limit value] came out to be the same number. There was this shocked look on their faces, like they were thinking, 'Wow, ... it really IS the same!'" (Interview 2/ October 16). Even though she thought it was sometimes harder for her to justify finding limit values analytically, Janet still insisted her students learn how to find the limit of functions using paper and pencil before using computing technology to find the limits. In her opinion, the ability to find limits analytically demonstrates students' understanding of the concept and their mathematical readiness to move to the next level.

Janet was not prepared to deal with the potential negative consequences of the use of technology in her classes, and so her experiences convinced her not to let her students use calculators. She observed that when she did allow graphing calculators to be used in class, she had difficulty motivating her students to find the limit values analytically. Her aim was to use the technology to create learning activities geared towards helping students develop an increased understanding of the concept. Instead of seeing her students manage their use of graphing calculators to further their mathematical understanding, however, Janet found that the students allowed the calculators to restrict what they learned. Janet said:

I think that graphing calculators are a wonderful tool for visualizing things, but some students tend to think of them as some kind of magic box that gives a correct answer, and it is very hard for them to come to terms with the limitations of it. (Interview 1/ September 5)

As a result of those setbacks, and in an effort to avoid such difficulties in the future, Janet concluded that she should not allow her students use calculators. Without calculators, her students could develop a proper understanding of the limit concept. According to Janet, the use of graphing calculators caused her students to lose sight of the mathematical goal of the lesson. Instead of attempting to internalize the concept, Janet said, her students used the calculators as a

shortcut that allowed them to bypass gaining an understanding of what they were actually doing.

She stated:

Calculators can give incorrect answers if students don't know what is happening. So, sometimes I think there are students who rely too much on them. There are plenty of students that don't want to learn and so they abuse the power they gain from the use of calculators. (Interview 2/ October 16)

Although both Ken and Janet had used various types of computing technology in their calculus instruction in the past, they had since decided not to use it anymore because of their observation of its detrimental effects on students' algebraic readiness. Through their classroom experiences, both Ken and Janet were convinced that computing technology was far more likely to interfere with, than to enhance, learning calculus. They claimed that the extensive use of graphing calculators could impede the acquisition of fluency in students' development of basic skills and computational procedures. So, although their initial attempts at technology integration derived from their desire to use technology to be more effective at getting their students to learn calculus, their experiences with such technology were problematic overall. Ken and Janet came to believe that using computing technology, especially calculators, was more of an impediment than an asset, and that belief stopped them from using such technology regularly.



## CHAPTER 7: SUMMARY, CONCLUSIONS, AND IMPLICATIONS

This study investigated the conceptions that different groups of calculus instructors had about teaching calculus with or without computing technology. For the purposes of this study, I adopted the definition of the word *conception* as a personal assessment of one's knowledge, beliefs, values, and concepts in a given domain. My initial interest for the study stemmed from an awareness of increasing availability of, and educational emphasis on, the integration of computing technology in calculus teaching and learning. I thought that a greater knowledge of these conceptions held by calculus faculty on the use of computing technology in calculus classes could influence the undergraduate education of future college professors. The four research questions guiding this inquiry attempted to answer what the conceptions of mathematics and learning mathematics were, why the professors chose to use or not to use computing technology, the implementation of teaching with or without technology, and how the professors in community colleges and universities differed in their teaching of calculus with or without technology.

Data collection strategies included classroom observations, interviews, and secondary data. The constant comparative method of analysis took place while the data were being collected, through an iterative coding process, and through writing the data stories of the calculus professors. Six calculus professors were purposefully chosen to participate in the study, and data stories were written about the participating professors in three groups. Among the research participants selected in each institution was a professor who was currently using computing technology in calculus classes, one who never used computing technology in calculus classes,

and one who had used computing technology in the past and had decided not to use it any longer. The stories of each group were written to reflect the conceptions of the professors: Their conceptions about mathematics, learning mathematics, and teaching calculus with, or without, computing technology were first described. Then the grounding of the professors' conceptions was discussed: their experiences with computing technology, their vision of the computing technology integration, the roles of computing technology in teaching and learning in the calculus classroom, and their concerns about the use of computing technology. Brief summaries of the similarities and contrasts between each of the three groups' two members were given at the end of each data story, and research questions were addressed through those data stories. The common themes that emerged were then analyzed in order to address the research questions in a more general sense.

### **Instructors Using Computing Technology**

The first research question was the following:

For instructors using computing technology to teach calculus,

- a. What are their conceptions of mathematics and learning mathematics?
- b. Why do they use computing technology?
- c. How do they use computing technology?

The conceptions of the faculty members had a strong influence on their methods for teaching calculus. This influence was evident in the decisions and techniques implemented in the classrooms, and the conceptions varied across the three groups. Adopting Ernest's (1989) categorization of an individual's mathematical philosophy, I concluded that the mathematical conceptions of the professors who were using technology were most aligned with the problem solver category: Mathematics is a continually expanding field of human creation and invention. I further aligned the professors' categorization through Rokeach's (1968) three components of a conception: the professors' cognitive, affective and behavioral dimensions of his or her

conceptions of teaching mathematics. The cognitive component of the professors' conceptions was their view that the subject was a quasi-empirical science, and they believed that performing mathematical research and teaching mathematics involved carrying out a substantial amount of experimental work before coming up with useful generalizations. The affective component of the conception was defined by the fact that the professors were actively engaged with their students, focusing on what the students were learning, and were responsive to their students' needs. They had a strong connection with their students and viewed them as individuals. The professors wanted to challenge each student as an individual rather than just the class as a whole. The behavioral component of the conceptions was defined by the perception of performing mathematics through carrying out laborious, deliberate experimental work. They saw learning mathematics as a process of inquiry and coming to know oneself, and defined their role of instructor as a facilitator whose goal was to ensure that their students would become confident in their ability to pose and solve problems.

The professors saw that the transition towards the use of technology would open up new ways to explore mathematics (Grassl & Mingus, 2007; Norton, McRobbie, & Cooper, 2000), in the same way that a microscope allowed biologists to explore life on a molecular level. Because they believed problem solving and trial and error were the best way to learn mathematics, they used technology to help students learn in that style. Fascinated by the connections between mathematics and other disciplines, they wanted their students to realize that mathematics really does make sense, and encouraged the students to perform in the classroom as mathematicians would through mathematical explorations. The professors were primarily focused on the interplay between seeing mathematics as a set of skills and procedures and finding value by applying it to the real world. Because they viewed mathematics as a subject that could be

implemented in other subjects as well as a tool to use in real-life problem solving, they concluded that technology could be used to strengthen problem-solving skills.

Like Ely (1999), the professors had been dissatisfied with the status quo, feeling a need to change. That dissatisfaction had motivated them to adopt and use computing technology for teaching and learning calculus. They believed that the use of computing technology allowed them to show connections between mathematics and other academic disciplines through real-world problems. They believed that learning mathematics required that students see and learn the application of calculus concepts and ideas in context. Their problem solver conception of mathematics made them realize that solving real-world problems from different academic disciplines could serve an important tool for getting students to be active in their calculus learning. They also saw that the use of computing technology allowed the students to take more initiative and become more independent in their calculus learning. In their experience, the use of the computing technology increased the students' motivation and engagement.

The professors had extensive experience with the available tools, and knowledge about the way they work. Because they were experienced with the tools, they believed strongly that the introduction of computers had provided new and powerful tools for doing mathematics. It helped mathematicians make new mathematical discoveries and develop new conjectures, and the application of applied mathematics methods had widened the scope and dimensions of mathematical research. These professors saw technology as an integral part of their students' lives, and they were aware of the fact that many of their students had used different computing technological tools before they came to college. Overall, the professors' journey towards integration of computing technology into calculus supported McCracken's (2008) findings that faculty would experiment with technology integration if they felt the integration of the

computing technology was consistent with their teaching style and conceptions of mathematics. These professors thought their students were knowledgeable and competently skilled, and they could see how it was pedagogically useful in students' learning of calculus. They saw that the nature of the technology design largely determined the impact of integration efforts on student achievement, and ongoing formative evaluations were necessary for continued improvements in technology integration.

These professors saw teaching as an opportunity for continual learning and growth; they constantly reflected on what they were doing and sought new ways to improve their teaching through revision of class activities and their choice of computing technology tools as well as the ways they used these tools in teaching and learning calculus. They believed that technology could, and should, be used to facilitate mathematical understanding and thus could be used profitably at most any stage of the calculus learning process as supported by several previous research findings (Dubinsky & Schwingendorf, 1991; Heid, 2002; Judson, 2007). The professors could help their students to develop an intuitive understanding of calculus by using multiple representations of the concepts through the use of computing technology. They believed strongly that technology should be constantly available to their students; the availability was intended to provide a variety of choices to both instructor and student. Because the faculty members felt a strong connection with their students, they decided to implement technology to better convey information in a form of learning that they thought the students were more accustomed to, as well as providing a means of better connection and relationship between the instructor and the student. The professors believed that the process of learning mathematics required problem solving and learning from mistakes, and they consistently implemented technology as learning tools in order to help better understand and teach the material.

As implied by Hamrick, Schuh, and Shelley (2004), the professors saw various opportunities to implement technology in the classroom and decided to capitalize on it in their instruction of calculus. From their perspective on teaching, these professors saw students as partners in the learning process, and they tried to develop a positive rapport with students by being sensitive to their aims for taking their classes as well as helping them to fill their knowledge gaps in algebra and precalculus concepts. They tried to accomplish that aim by providing certain Web page links for reviewing these concepts, by encouraging students to come to them during office hours, and by paying special attention to students' questions by not dismissing any information or a particular step in algebraic simplification. They used technology for various purposes including communicating with their students, making class notes available online for them to review later, motivating them to learn concepts, and showing the applications of those concepts in various academic disciplines. The professors took opportunities to demonstrate the ways that technology could be used by finding the function of a line tangent to the function  $f(x)$  at point  $X$ , the average rate of change of a function, the mean value theorem, Rolle's theorem, and using the secant method for solving equations. They used various computing technologies for in-class demonstrations and students' explorations in order to help them develop an intuition for calculus concepts and processes. These professors tried to graph functions and their derivatives simultaneously to help their students see the intuitive connection between a function and its derivative. They also used technology to help students visualize abstract concepts and provide a dynamic representation of the idea of convergence, such as showing how the secant line becomes a tangent line as  $\Delta x$  goes to zero. These instructors saw the opportunities that technology had to offer, and took full advantage of it in their instruction. They used the zoom feature of a calculator to narrow in on a graph so that students could understand

the concept of local linearity when learning about the derivative and linear approximations. They constantly searched for creative ways to integrate technology such as using it to plot a Valentine's Day card by graphing polar equations and using Newton's method to find solutions to equations that were derived from mathematical models in problems from different disciplines. In that environment, the faculty members could turn to technology whenever they deemed it valuable or appropriate. Similarly, during certain classroom activities, students were given the option of using technology or not, and the professors were adamant that their students be allowed to use computing technology in all situations.

### **Instructors Never Using Computing Technology**

The second research question was the following:

- For instructors who never use computing technology to teach calculus,
- a. What are their conceptions of mathematics and learning mathematics?
  - b. Why do they not use computing technology?
  - c. How do they teach calculus without using computing technology?

The faculty members who never used technology in the classroom were most aligned with Ernest's (1989) platonist view: mathematics is a unified body of certain knowledge. The cognitive component of Rokeach's (1968) definition of conception in regards to these professors was the thought that mathematical knowledge was pure and timeless, and that it had universal validity. They liked the subject because it was very logical and required precise thinking, and were motivated by intellectual curiosity and a desire to know the truth. The affective component of their conceptions was defined through their belief that the study of mathematics is beautiful and pure. These professors saw mathematics primarily as an elegant intellectual achievement and an analytical tool that represents the world in symbolic forms, and as a hierarchical subject that builds upon what one has already learned. The behavioral component of their conceptions was demonstrated through their attitudes of performing proofs and exercises as the best way to learn

mathematics, and they thought teaching mathematics was mainly about teaching students to think clearly and logically. For them, the role of the students was to learn the fundamentals, and each one of their students needed to be equally willing and prepared to learn the fundamentals of mathematics. These instructors equated the aptitude of performing mathematics and developing their skills to the talent and patience of artists or musicians: you either have it or you do not (King, 1992; Poincaré, 1910). Because they considered mathematics as a timeless and pure science, they believed that technology only got in the way of an already perfected strategy of learning mathematics. They believed that students' algebraic preparedness was necessary for learning calculus, and poor performance was indicative of a lack of knowledge, preparedness, or willingness to succeed in the field. Thus, they treated the student body as a whole, rather than focusing on the individual.

Seeing themselves as explorers of mathematics, these professors loved the challenge of understanding abstract concepts, and saw the practice of mathematics as a form of self-growth. Though the professors did believe that to some extent the real-world application of mathematics was also important, they described mathematics primarily as a way of thinking. They said that developing fluency with symbolic manipulation and basic skills was necessary since students needed to have those skills to communicate and learn more advanced concepts. According to these professors, mathematics was essentially an abstract subject, and it should be taught as a set of concepts, skills, and calculations. They emphasized developing students' reasoning abilities, which they defined as a line of thought and a way of logical thinking, adapted to producing assertions and reaching mathematical conclusions. They saw mathematical reasoning as objective and rigorous, and believed students should be able to use their own logic without the use of technology for reflection, explanation, and justification.



Because they viewed mathematics as a pure science and theory, these professors concluded that technology would be of no use to their calculus teaching. They were mainly concerned with helping students to develop a conceptual understanding of calculus concepts and believed that the presence of computing technology prevented them from achieving that goal. This finding was in line with E. M. Rogers's (1995) theory of relative advantage. Rogers argued that even if individuals are exposed to innovation messages, such exposure will have little effect unless the innovation provides some advantage over the traditional ways of doing things. Furthermore, McAlpine and Gandell (2003) argued that even if individuals were exposed to innovation messages, such exposure would have little effect unless the innovation was perceived as relevant to the individual's needs and consistent with the individual's attitudes and beliefs.

A key reason that the professors chose not to implement technology was that they had limited knowledge about computing technology tools. They knew how to use some computer software to do mathematical investigations and for graphing, but they had very limited knowledge about using graphing calculators and were not knowledgeable about the existence of various Java applets or Web pages to conduct mathematical explorations or demonstrations of calculus concepts. These professors further believed that the early introduction to, and extensive use of, calculators had hindered their students' development of number sense and algebraic skills. They thought it was unacceptable for students to be unable to perform basic arithmetic and symbolic manipulation by hand. By not letting their students use computing technology in their calculus classes, these professors intended to force the students to develop those skills. They thought students should have mastered fundamental skills and concepts before they started to use computing technology for learning mathematics. Although they were categorically opposed to using computing technology in first- and second-semester calculus, these faculty members were

open to its use in upper level mathematics courses. As demonstrated by the findings of LaBerge, Zollman, and Sons (1997), some mathematicians believed that students were not sufficiently knowledgeable about the subject to utilize the use of computing technology in calculus instruction. These professors believed that progressive knowledge development was the key to long-term progress in mathematics and, with their emphasis on proofs and deriving the relationships, they believed that they were helping students to gain a solid grasp of basic knowledge and techniques. The professors' insistence that the students needed to be better prepared before entering the calculus classroom shaped their decision to not use technology, as that would be using a method that was unnecessary for learning.

Adamant that the use of technology was unnecessary, and perhaps even detrimental to a student's learning of calculus, these professors chose to teach using more traditional methods. They emphasized exploring mathematics through its concepts, and doing mathematical proofs served that purpose most efficiently. They were most concerned with helping students to develop a conceptual understanding of mathematical knowledge through doing mathematical proofs and asking students to provide logical arguments. As Hersh (1997) explained, a professor presented mathematics in the same way they understood mathematics. These professors were interested in sharing what they found beautiful in doing mathematics, believed that calculus should be taught more traditionally, and decided that technology would get in the way. Their instruction was focused on providing mathematical proofs and logical deductions. In their classes, they regularly presented mathematical proofs of calculus concepts including the chain rule, the mean value theorem, and the fundamental theorem of calculus. During their demonstration of proofs, they tried to engage the students by asking questions. When a student asked a question during class, they generally tried to answer it with more questions, believing that this process allowed them to

gauge each student's current mathematical conceptual framework. They were also quite adamant about showing the derivation of mathematical concepts and ideas from previous ones. In their classes, they constantly showed the derivation of trigonometric identities when their use was required in solving problems to demonstrate how mathematical ideas were related. Their aim was to convince students that while working on problems in the classroom and on exams, the solutions should be fully simplified at the end. They insisted that students should have known the unit circle values, and they chose classroom exercises and examination questions so that the result would exactly correspond to reference angles.

Their teaching can be summarized as starting with the delivery of the lecture by presenting relevant ideas and theories and hoping that their lecture and the use of concrete examples would help students to digest the concepts and ideas. They also assigned enough exercises when they believed that a successful completion of assigned problems would help students to develop fluency with related skills and get ready to wrestle with more abstract concepts. They saw that examinations and assignments were ways to help students understand their progress in learning calculus and helped to self-evaluate their teaching. If they saw a pattern of misunderstanding or observe logical deficits of their students, they tried to remedy the issues through their lectures.

### **Instructors Who Once Used Computing Technology**

The third research question was the following:

- For instructors who once used computing technology to teach calculus,
- a. What are their conceptions of mathematics and learning mathematics?
  - b. Why do they no longer use computing technology?
  - c. How do they teach calculus without using computing technology?

The conceptions of the faculty members that had used computing technology in the past and decided not to use it anymore aligned most with Ernest's (1989) instrumentalist view of

mathematics; they saw learning mathematics partly as an accumulation of facts, rules, and skills in the pursuit of understanding mathematical concepts. In regards to Rokeach's (1968) three components of a conception, the cognitive component of the professors' conception was their view of learning mathematics as hierarchical and as a process of making connections between new and previously learned ideas. The affective component of their conception was their view that incorporating technology into the classroom had proven to be too time-consuming and troublesome. In addition, they viewed their students as too intellectually immature to use technology responsibly. The behavioral component of their conception was that they taught mathematics to help students achieve a mastery of designated skills and a level of mathematical understanding.

The professors who had abandoned the use of technology in the classroom were very similar to those who had never used it. They believed that the instructor's role was to deliver the content by giving appropriate lectures. They believed that their students were not intellectually mature and were perpetually in a state of learning. As a result, they adopted a belief in line with Quinlan's (2007) study demonstrating that a majority of mathematics professors believed that the use of the computing technology was better suited to teaching rather than learning. They wanted their students to understand the importance of the reasoning behind the problem, and they believed that the job of the students was to observe and absorb. Furthermore, they had the view that the students were not intellectually mature enough to learn to use computing technology to further their mathematical understanding. This conception was supported by LaBerge et al. (1997), who demonstrated that some mathematics faculty members believed that some of their students were not ready for implementing the pedagogical techniques that required more initiative for the students to perform independent explorations. Although they might have liked

to include activities involving the use of computing technology to help the students to learn mathematics, these professors believed that many of the students were not prepared by their previous education experience to participate in such activities. These professors observed that their students would often use technology without a defined or purposeful strategy, thus resulting in an overreliance on the technology (Doerr & Zangor, 2000; Forster & Taylor, 2006). Like those who never used technology, these professors focused more on the class as a whole rather than on the individual students in it.

The professors thought that the main goal of teaching mathematics was to help students achieve mastery of designated skills and a level of mathematical understanding. They claimed the use of a graphing calculator hindered the students' ability to read and interpret the graph, and some students' inability to see the first derivative as a function made it harder to understand the relationship between the first and second derivatives. They said that they had initially envisioned the beneficial effects of technology on instruction and students' learning as issues that had motivated them to adopt and use technology to help students develop a deeper understanding of calculus concepts. However, after their attempts at integrating technology into the classroom, they developed misgivings about the use of computing technology and decided that it was not helping their students develop a better understanding of calculus concepts. On the contrary, these professors felt that the use of technology had hindered the students' mastery of fundamental algebraic, arithmetic, and calculus skills. They wanted to help students acquire mathematical habits of mind, and they believed the use of computing technology hindered that process because it replaced students' mathematical understanding.

These professors had experience with the tools they wanted to use but thought the time spent on teaching students how to use computing technology to conduct mathematical

investigations was not worth it, because it took away time they could use teaching them fundamental skills and concepts. Furthermore, they claimed that the majority of their students were already anxious about learning the abstract concepts of calculus, and requiring the use of computing technology for calculus investigations would create extra pressure on those already anxious students. During the time these professors were using technology in the classroom, they observed that some of the students would become confused and spend more time working on the issues with the computing technology rather than on using it to make progress in their mathematical understanding, as noted by Graham and Thomas (2000).

After their technology integration attempts, these professors came to believe that their students lacked the maturity to use computing technology to conduct mathematical explorations, and they did not want their students to develop an overreliance on the calculator. This perception made them consider continuing to use technology to teach calculus concepts while not allowing their students to use technology to work through the problems. Ultimately, these professors became convinced that students should not be allowed to use technology tools in their learning because their use prevented the students from developing basic skills and understanding. They noted that the use of computing technology in learning calculus without having achieved a mastery of basic concepts and skills caused students to develop a false sense of confidence in their ability to perform mathematics.

Although these professors had implemented technology at one point in their teaching careers, they eventually realized that the use of technology was a poor substitute for time-tested teaching methods. At the time of data collection, these professors were teaching in much the same way as those who had never used technology in calculus instruction, utilizing a much more traditional method. They delivered the lecture, presented the ideas and theories, and tried to use

concrete examples. They thought that when the instructor gave examples, they could capture students' attention and make it easier for them to remember a conceptual element. In their teaching, these professors structured the subject matter in such a way that students had to see each detail as a part of an integrated whole. The students' roles were reactive; that is, they were asked to internalize patterns of thought explained to them by the instructor, and then to make those thought patterns a part of their own mathematical knowledge. In class, these professors worked examples similar to those they assigned for homework. They believed grading had to give points to students who had demonstrated an attempt to improve their ability to perform mathematics, and they allowed the students to resubmit the assignments.

These professors insisted that students should have learned calculus ideas and concepts with paper and pencil first, and that faculty should not use technology until after the students already knew how to do the mathematics by hand. They believed that students needed to have a solid understanding of fundamental mathematical concepts, and that technology could be used to enhance that understanding later. This conception was illustrated well through their conceptions about students' learning of graphing and the limit concept. They wanted their students to know how to graph and find limits of functions by hand. The professors thought the role of technology in calculus instruction should always be supplementary; it was important to them that the technology not be constantly available to the students, and they did not want technology to be perceived as the primary source of instruction. Furthermore, they were convinced that students should not have used technology before they had mastered basic skills and knowledge, in the same way that a student driver is allowed behind the wheel of a car only after passing a written exam demonstrating that he or she had the required basic knowledge of traffic rules.

## **Instructors in Community Colleges or Universities**

The fourth research question was the following:

How do instructors in community colleges and universities differ in their teaching of calculus with or without computing technology?

Among the three groups examined, their conceptions shaped the decision of whether or not to implement technology in the classroom, and helped define the methods each used to teach calculus. These decisions in the classroom were further defined depending upon whether the calculus class was offered at a large university or a smaller community college. The degree of emphasis placed on teaching norms significantly varied between the community college and the university (J. M. Boyer, 1997; Surry & Land, 2000). The main source of these differences could be attributed to their mission, along with their student and faculty populations (Hagedorn, Maxwell, Cypers, Moon, & Laster, 2007). For example, the average number of students enrolled in calculus classes at the community college was significantly lower than at the university. Furthermore, because of the main difference between these academic institutions' missions (teaching vs. research), the community college calculus instructors were required to have more office hours per week compared to university instructors (12 hours at Fairway vs. 3 hours at Braun). These conditions, along with differences in student body demographics between the schools, affected the way that technology could be implemented in the classroom.

As an open-access institution, Fairway College provided educational opportunities to a wide spectrum of students, including providing educational opportunities for traditionally low achievers (Bowen, Chingos, & McPherson, 2009; Burke, 2005). The faculty all agreed that many students did not possess sufficient knowledge or skills involving algebraic concepts, and said that a lack of algebraic readiness would be a significant barrier to succeeding in calculus. However, some instructors also noted that previous mastery of algebraic concepts was not the only



indicator of potential success in learning calculus, as a student's desire to learn would also affect their ability to be successful in calculus. Certain restrictions between the two types of institutions shaped the decision of whether or not, as well as how, to use technology in the classroom. Compared with the university, the community college had much less freedom and more restrictions regarding the use of certain computing technologies and assignment techniques. The university professors had fewer restrictions and could teach as they pleased, but certain restrictions in the community college, such as the department's policy of prohibiting the use of the TI-89 graphing calculator and the TI-Inspire, hindered at least one instructor's decisions. That instructor did not believe that the use of advanced calculators interfered with her students' abilities to learn calculus concepts, and could in fact strengthen their understanding of more difficult concepts, but she was forced to comply with the department policies. With the use of superior calculators, instead of focusing on symbolic manipulation, students could pull away from the more concrete aspects and stick to the more abstract theoretical concepts of calculus. In addition to certain technological restrictions, the instructor was also required to conduct an in-class exam, when she would have preferred to assign a project to the students using real-world applications. When working in an open access institution like a community college, some faculty members also thought that it was necessary to make changes in their instructional methods. For example, one faculty member felt obligated to teach students how to use an instructional program, Maple, to better prepare those who would chose to move on to larger institutions that made use of the program.

Faculty members at both institutions were in favor of offering different sections of calculus to help overcome certain difficulties. They all agreed that the current generic calculus classes were difficult to teach because they were required to accommodate numerous students'

needs, which varied in terms of their mathematical background, skills, personal experiences, and the expectations of their academic disciplines. They all also complained about the difficulty of finding class activities and problems that were relevant to students' academic disciplines, as many were not primarily focused on mathematics. The professors also felt the pressure of implementing a differentiated calculus instruction that was responsive to students' needs and expectations, and they observed that current traditional calculus classes did not really serve the needs of students. Although some faculty members were categorically opposed to the idea of integrating computing technology into their current generic calculus classes, they were open to the idea of exploring the educational opportunities involved in integrating computing technology into the other sections of calculus. However, one professor in the university was concerned with the possibility of offering different sections of calculus based on the student population without sacrificing the rigor of these calculus sections.

In summary, the contextual conditions in their teaching environments appeared to have some impact on professors' technology integration decisions. This finding is supported by the assertions of Surry and Ely (2006), which stated that the process of technology integration was consistent with the policies and missions of a given institution. The faculty members' conceptions of mathematics, their conceptions of learning mathematics, and their attitudes and beliefs towards technology were the primary agents when they made decisions about the integration of computing technology into their calculus teaching regarding activities and lecture structure (Hamrick et al., 2004; Hersh, 1997). The professors' concerns about teaching with technology could be categorized into two main areas: instructor responsibility and student responsibility. The more a professor wanted to focus on conceptual understanding and wanted students to take responsibility for that understanding, the more the professor was concerned

about his or her own instructional techniques to facilitate such learning and the need for the availability of computing technology. The more a professor focused on procedural understanding in calculus and on teacher-centered lessons, the more he or she was concerned with students misusing the computing technology and failing to learn fundamental skills, concepts, and procedures. The most important issues found among professors in this study were the expectations of success and the perceived value of differentiating levels of computing technology usage. The professors who were users of technology tended to have more positive attitudes about technology integration, to have higher motivation for using technology, and to have more positive perceptions of the effects of technology on students' learning of calculus. They were more knowledgeable about the pedagogical opportunities and constraints of a wide range of different technological tools. Furthermore, they had a deeper understanding of the manner in which the subject matter could be presented, and the types of representations that could be constructed and changed by the integration of computing technology. The faculty members' conceptions of mathematics also appeared to have a strong influence on the methods they used to teach calculus. This influence was evident in the faculty members' educational decisions and the techniques they implemented in their classrooms. The impact that their conceptions of mathematics had on their teaching was comparable to a chef's conception of a good meal; the ingredients he or she chooses, along with the amount and type of seasoning and the cooking technique he or she uses will all contribute to the creation of a fine meal.

### **Implications for Calculus Instruction**

This study revealed that some instructors were not aware of the various roles that technology could play in teaching and learning calculus. Although previous research studies of undergraduate mathematics education provided abundant evidence and possible opportunities,

the calculus professors were not aware of the existence of those studies. There is a strong need for sharing these research findings with the faculty through professional development opportunities. The faculty need to see that technology can play important roles in teaching and learning calculus to become convinced that the use of computing technology could motivate students and help the students' development of procedural and conceptual understanding of calculus. The faculty could start seeing that the use of technology could also be motivational to students in that students would be more interested in learning mathematics when technology was involved in the process. The use of computing technology could encourage students' involvement through implementation of various real-world problems in classroom activities.

In this study, while all faculty members were aware of the procedural roles that computing technology could play, some were not aware of the conceptual roles that it could also play in calculus instruction. These conceptual roles include demonstrations, illustrations, visualizations, and explorations, as well as making connections to other mathematics as well as to the real world. The professors needed opportunities to see that the use of computing technology could serve as a medium through which the students would come to understand a mathematical concept. They also needed opportunities to see how its use could help illustrate mathematical concepts that might otherwise seem extremely abstract so that they could start developing appreciation for the power technology has for allowing students to visualize mathematics—to see things that they might not otherwise see. Calculus professors need to see how the use of multiple representations, tables and algebraic procedures, when done multiple times in close proximity, become dynamic representations of the big picture of teaching calculus. And, then, technology becomes a tool that they turn to both powerfully and naturally when it is used to allow students to discover, and for the faculty to show, a mathematical relationship.

Furthermore, the students' success stories should be presented to convince the faculty of how technology might help students get beyond procedures and see the big picture. In this study, some faculty members also expressed their concerns regarding the existence of technology and students' basic skill development and their understanding of basic concepts. Several mathematics education research studies with undergraduates demonstrated that the integration of computing technology did not interfere with students' basic skill development and could have been introduced (Heid, 1988; Hillel, 1993), and the presentation of these studies in tandem with students' success stories and activities might challenge some faculty members' perception of learning mathematics as a hierarchical process. In this study, some faculty members also expressed their willingness to try to integrating technology into their calculus classes if they were not teaching the generic version of calculus, which made it difficult to integrate computing technology and still be responsive to different students' needs. There is a need for mathematics departments to explore further the feasibility of offering different sections of calculus for different clientele. Furthermore, the department should also search for opportunities for the input of different academic departments regarding their expectations from calculus classes and search for opportunities to make their calculus curriculum more responsive to their needs and expectations.

The successful integration of computing technology into calculus classes requires having a clear departmental vision of the computing technology integration and the expectations from the faculty to implement such a vision. Creation of such a vision requires getting the faculty members' input, addressing their concerns, and communicating the departmental expectations clearly regarding its implementation. In this vision, the need for aligning the classroom practices with the use of computing technology and the technical support for the faculty, as well as the

department commitment to help professors gain the necessary technological knowledge and expertise to integrate technology into calculus classes, should be addressed. In this study, some faculty members said that such a vision and commitment on the part of academic administrators in terms of firm and visible evidence of continuing endorsement and support for technology integration seemed to be lacking or at best half-heartedly practiced. One of the ways to motivate calculus faculty members to integrate computing technology into their calculus classes would be to require technological skills and use in teaching as part of faculty evaluation. If faculty members are aware that the use of technology in their instruction is part of their evaluation for tenure, they might view the implementation of technology more seriously and invest the time and effort needed to take the initiative towards integration. That policy would call for the integration of technology into the curriculum and instruction and at the same time would make sure the contextual conditions for the implementation of educational innovations are in place. Mathematics departments might also consider the setting up of educational technology standards to guide faculty in their technology integration activities.

Although this study implied that successful technology integration had proven benefits, some professors still had some misgivings about its implementation. These instructors believed that technology would essentially perform the work of students for them, and not allow them to grow intellectually as mathematicians. Additionally, because a strong fluency in the use of technological tools was necessary for successful implementation, too much time would be spent learning to use these tools rather than learning mathematical concepts. The professors who shared these misgivings seemed to have a time-tested method of teaching calculus concepts, and the inclusion of technology in institutional policies would affect their ability to teach in the methods that they were accustomed to. They had their own teaching methodology, and it had

been proven successful in their eyes—and their methodology may have been successful. Because some never used technology in the classroom before, their understanding of available tools was limited. There was a steep learning curve for some software packages. The research and investment necessary to understand and integrate computing technology in calculus would be time consuming. These professors saw that the integration of technology could negatively affect their opportunities for rewards through promotion or chances for tenure, or perhaps they did not see the future of technology. The integration of computing technology policies should be effectively communicated to them, and they should be given enough support to make a smooth transition, through demonstrating its value and supporting it with evidence of its benefits.

### **Implications for Further Research**

As much as is known about an instructor's concept of mathematics and computing technology and the role it plays in his or her instructional practice, much more remains unknown and must be revealed through study and observation. This study's potential to find answers to a number of important questions was limited, as the research in each classroom was conducted during a single course. Consequently, it was not possible to examine in depth whether differences in the composition of the calculus classes had any relationship to the differences in the instructors' professed conceptions. Therefore, more questions remain. How do instructors demonstrate their views of mathematics and computing technologies? Are the instructors' views communicated explicitly or implicitly? If instructors can effectively demonstrate their views, do differences in the instructors' concepts have any effect on their students' perceived abilities to learn calculus?

This study discovered the difference among instructors based on their level of reflection on their previous practices. Their formal and informal pedagogical training had affected their

reflection on instructional practices. Several instructors approached their teaching methods without any formal or informal pedagogical knowledge and justified their reasons with previous personal experience (e.g., I did it that way last time and it worked), rather than an instructional principle (e.g., providing examples is helpful for student learning). The instructors who did not possess much pedagogical knowledge were prone to focus on how the students appeared to respond to the teaching and the material, rather than focusing on what they might or might not have learned. Without using pedagogically based reflection, those instructors tended to draw solely on their previous personal experience. Further study is required to reveal how instructors' pedagogical training affects their instructional practices.

This study also confirmed that instructors' conceptions of mathematics affected their instructional practices, depending on each instructor's individual experiences and his or her level of reflection. Their conceptions of mathematics partly determined what they thought a student had to know after successfully completing a calculus class. The importance an instructor placed on practicing mathematical proofs in calculus classes also proved to affect his or her instructional practices and pedagogical decisions, which was evident by the instructor's choice of projects and whether or not his or her students were allowed to use computing technology. There is a need to investigate further the effect that performing mathematical proofs has on students' learning in calculus classes. Furthermore, there is a need to investigate how instructors emphasize the importance of doing mathematical proofs in calculus classes and how it affects their students' performance and attitudes.

The study also revealed that the instructors tended to base their instructional strategies and technology integration decisions on their students' perceived maturity and their algebraic understanding. If an instructor thought his or her students were not mature enough to handle the



Introduction to Calculus course or that they did not possess the prerequisite algebraic knowledge base to succeed, the instructor tended to refrain from integrating technology into the calculus class or did not let the students use computing technology tools in their learning. The connection between instructors' perception of their students as learners and their instructional and technology integration decisions needs to be explored further. In a similar vein, further investigation is required to understand the complexities of students' previous knowledge base and the impact it has on an instructor's instructional and technology integration decisions.

This study's findings also presented evidence to demonstrate that the instructors' notions of computing technology as well as their visions of the impact technology has on everyday life, college students' life, and the higher education environment were determining factors in the instructor's decision to integrate computing technology into calculus teaching. Most of the instructors chose their technology integration methods based on their previous experiences. The majority of instructors wanted to see successful computing technology integration demonstrations, either to learn more about the benefits and to become convinced about the integral part that computing technology could play in teaching calculus, or, for those who were already using it in their classes, to learn and explore different activities or pedagogical approaches. The calculus instructors asked to see content-specific applications and demonstrations of computing technology integration. With these factors in mind, mathematics departments should strive to organize relevant workshops and professional development activities for the faculty, both to introduce the faculty to new methods and to give them an opportunity to see how the methods operate.

Most of the faculty members in the study stated that time was the main constraint that prevented them from integrating technology into their classrooms or improving their current

practices involving computing technology, which explained their reluctance to dedicate time to integrate or explore different ways to integrate computing technology in their calculus classes. The instructors in the research university believed that they would be evaluated on the quality of their publications. Thus, they wanted to devote the majority of their time to research, as opposed to learning or discovering novel ways to integrate computing technology into their classrooms. The tenure-track faculty member was especially under a lot stress and time constraints because of the arduous process of establishing a solid profile as a teacher, a department member, and a scholar. Further study is required to examine research universities' mathematics instructors' perceived responsibilities regarding teaching, research, and service. How do they perceive and interpret the different dimensions of their job? Is there a connection between the instructor's perceived responsibilities and his or her instructional strategies and decisions? The community college faculty members also complained about the time-consuming job of computing technology integration and lamented the fact that they did not receive any recognition or perks for their attempts to integrate technology into their classes. In order to foster a more supportive environment for faculty members attempting to integrate computing technology into their classrooms, mathematics departments should offer incentives, such as time off or other rewards, and organize workshops to provide support and encouragement to the faculty. The faculty promotion and evaluation criteria should include and value the faculty's computing technology integration initiatives. To encourage faculty members to integrate technology, for example, mathematics departments should also allow instructors to contribute their opinions to create a clear vision of technology integration and should articulate their expectations regarding the faculty's responsibilities to implement such a vision.

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## APPENDIX A: INITIAL SURVEY

Dear Instructor,

I am a community college mathematics instructor pursuing my doctoral degree under the direction of Dr. Jeremy Kilpatrick in the Department of Mathematics and Science Education at the University of Georgia. I am conducting research to study issues related to the use of computing technologies (computers and graphing calculators) in calculus teaching. I am requesting your participation in this study. Would you please offer your expertise by completing the attached questionnaire? It will take 5 to 10 minutes of your time. Please know that your contribution about what you think about the use of computing technologies (computers and graphing calculators) will be invaluable. When you finish, please send the file to me via email. If possible, could you please try to complete the questionnaire by August 17, 2008?

Return of the questionnaire will be considered consent for participation. Please note that you will *not* be asked to provide your name. At the top of each questionnaire you will find a number that I have assigned to each instructor for tracking and coding purposes. As the researcher, I alone will know which instructor the returned questionnaire is from. The results of the study will be a public record, but neither the instructor's name nor his or her affiliation will be revealed.

As a current mathematics instructor, one of my goals for this research study is to find practical and employable strategies for technology integration. The information that you provide me by completing the questionnaire will greatly improve the relevance of my findings. Your participation in this study is completely voluntary. I know firsthand how precious time is in the daily life of a math instructor. I am therefore extremely appreciative of the time that you are taking to complete the questionnaire. Additionally, I would be happy to provide you with a copy of my results if you would find it useful. If you have any questions or concerns please feel free to e-mail me at (hserkan@uga.edu) or call me at 706- 202 4742.

Thank you in advance,

Serkan Hekimoglu

What is the TOTAL number of hours a week that you spend on a computer?

0      Less than 1      1-5      5-9      10-14      15-19      20-29      30+

On what activity do you spend most time when using a computer? (check **ONLY ONE**)

email	word processing
surfing the internet	doing mathematical research
preparing for my classes	playing games
researching things unrelated to school	Other -----
using in my classes	

How would you rate your level of experience with graphing calculators?

Very Limited      Basic      Intermediate      Advanced      Expert

How would you rate your familiarity with the CALCULUS REFORM MOVEMENT?

Never Heard of      Limited      Average      Above Average      Highly Familiar

Please indicate how strongly you agree or disagree with each statement.

The instructor should find ways to use computing technologies (computers and graphing calculators) in their classroom.

Strongly Disagree      Disagree      Neither Disagree nor Agree      Agree      Strongly Agree

Students should have access to computing technologies (computers and graphing calculators) at any time during the instructional day.

Strongly Disagree      Disagree      Neither Disagree nor Agree      Agree      Strongly Agree

Every mathematics instructor should provide assignments that require using computing technologies (computers and graphing calculators).

Strongly Disagree	Disagree	Neither Disagree nor Agree	Agree	Strongly Agree
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Computing technologies (computers and graphing calculators) HAVE changed how we teach calculus.

Strongly Disagree	Disagree	Neither Disagree nor Agree	Agree	Strongly Agree
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Computing technologies (computers and graphing calculators) WILL change how we teach calculus.

Strongly Disagree	Disagree	Neither Disagree nor Agree	Agree	Strongly Agree
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How frequently do you use computing technologies (computers and graphing calculators) in your teaching of mathematics?

Never	Rarely	A fair amount	Usually	Every lesson
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What barriers do you see to using computing technologies (computers and graphing calculators) in your classroom?

## **APPENDIX B: INTERVIEW PROTOCOL**

### Interview Protocol I

1. What do you especially enjoy about mathematics?
2. What do you see as your ultimate responsibility as a calculus instructor?
3. What kind of technologies do you use in your calculus class? How comfortable are you using them? Do you have concerns about using computing technology in your class?

If you are not using any computing technologies, what are your reasons for not using them?

4. Are your students using computing technologies in class? What about outside class? If so, what are they? What are your feelings and policies?
5. Do you think your class is better with(out) using computing technologies? How?
6. Complete the sentence, “ I would use computing technologies if ...”
7. Describe any guidelines, imposed by the mathematics department, that relate to teaching differential calculus as well as using computing technologies. How do you feel about those guidelines?
8. What do you believe are the overriding purposes and aims of teaching differential calculus?  
What do you feel are the most important calculus concepts and skills for students to learn? Why?
9. In what direction do you believe calculus teaching is moving at the college level?
10. How do you feel about teaching separate differential calculus sections for different majors such as engineering and business?
11. Do you think computing technologies need to be adjusted for these different sections? Why or why not? And, how?

## Interview Protocol II

1. What is the impact of technology on modern society?
2. If technology were an animal, what would it be? Why?
3. What does it mean to teach calculus with technology?
4. Did (Would) computing technologies have an impact in the undergraduate mathematics classroom? How so?
5. Do computing technologies impact students' mathematics learning? If so, how? If not, why not?
6. What is the biggest advantage to using computing technologies in teaching calculus? What about the biggest disadvantage?
7. Do you have a vision or image of teaching differential calculus with computing technologies? If so, could you describe it?
8. What are (or might be) the computing technologies most helpful to you? What topic(s) and what kind of activities? What are the problems that you have experienced? Are there any calculus concepts with which you feel it is necessary to use technology?
9. Describe your earliest experience teaching calculus with computing technologies. What is the most positive experience you have had using computing technologies? What about the most negative? What are some situations when you definitely would not use computing technologies in your calculus teaching?

## APPENDIX C: TIMELINE OF DATA COLLECTION

Table 2: Data Collection Activities

Date	Activity	Instructor
August 14, 2008	Survey administration in both institutes	
August 25, 2008	Participants recruited	
September 5-18, 2008	First interview conducted with all participants	
September 7, 2008	Classroom observation–limit	Lynn
September 8, 2008	Classroom observation–limit	Joe
September 11, 2008	Classroom observation–limit	Ken
September 12, 2008	Classroom observation–limit	Ron
September 12, 2008	Classroom observation–limit	Janet
September 13, 2008	Classroom observation–limit	Dorothy
September 13, 2008	Classroom observation–continuity	Ron
September 19, 2008	Classroom observation–derivative	Lynn
September 21, 2008	Classroom observation–derivative	Ron
September 21, 2008	Classroom observation–derivative	Janet
September 22, 2008	Classroom observation–derivative	Dorothy
September 22, 2008	Classroom observation–derivative	Ken
September 26, 2008	Classroom observation–derivative	Janet
September 29, 2008	Classroom observation–derivative	Joe
October 3, 2008	Classroom observation–related rates	Ron
October 3, 2008	Classroom observation–linearization	Janet
October 4, 2008	Classroom observation–related rates	Dorothy
October 5, 2008	Classroom observation–related rates	Lynn
October 6, 2008	Classroom observation–linearization	Joe
October 6, 2008	Classroom observation–related rates	Ken
October 10, 2008	Classroom observation–related rates	Ron
October 16-31, 2008	Second interview conducted with all participants	
November 8, 2008	Classroom observation–Mean Value Theorem	Joe
November 9, 2008	Classroom observation–optimization	Lynn
November 13, 2008	Classroom observation–curve sketching	Dorothy
November 14, 2008	Classroom observation–optimization	Janet
November 14, 2008	Classroom observation–curve sketching	Ron
November 16, 2008	Classroom observation–curve sketching	Lynn
Dec.18, 2008-Jan.19, 2009	Third interview conducted with all participants	
February 6, 2009	Classroom observation–derivative	Ken
February 14, 2009	Classroom observation–related rates	Joe
February 14, 2009	Classroom observation–The Intermediate Value Theorem	Lynn
March 21, 2009	Classroom observation–linearization	Ken
March 21, 2009	Classroom observation–Newton’s Method	Joe
March 22, 2009	Classroom observation–Bisection and Newton’s Method	Dorothy
March 23, 2009	Classroom observation–Rolle’s Theorem	Joe
April 10, 2009	Classroom observation–curve sketching	Dorothy
April 10, 2009	Classroom observation–curve sketching	Lynn



April 11, 2009  
April 12, 2009

Classroom observation–optimization  
Classroom observation–optimization

Janet  
Dorothy

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