A mixed methods study of the effects of clicker use on math anxiety and achievement in mathematics

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A mixed methods study of the effects of clicker use on math anxiety and achievement in mathematics

by

John H. Batchelor

A dissertation submitted to the graduate faculty in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY

Major: Education

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Iowa State University
Ames, Iowa

2016

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DEDICATION

This
dissertation
is dedicated to
my parents, Webb and Martha Batchelor,
who have taught me the life skills, values, and work ethic
necessary to persevere throughout my formal education—
from my first day in kindergarten
through the final stages of editing and revising my doctoral dissertation
and receiving the Ph.D.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF FIGURES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>viii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ix</td>
</tr>
<tr>
<td>CHAPTER 1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Major Topics and Definitions</td>
<td>2</td>
</tr>
<tr>
<td>Problem Statement</td>
<td>4</td>
</tr>
<tr>
<td>Conceptual Framework</td>
<td>5</td>
</tr>
<tr>
<td>Research Questions</td>
<td>6</td>
</tr>
<tr>
<td>Purpose Statement and Overview</td>
<td>7</td>
</tr>
<tr>
<td>Significance of the Study</td>
<td>8</td>
</tr>
<tr>
<td>Organization of the Dissertation</td>
<td>9</td>
</tr>
<tr>
<td>CHAPTER 2. LITERATURE REVIEW</td>
<td>10</td>
</tr>
<tr>
<td>Conceptual Framework</td>
<td>12</td>
</tr>
<tr>
<td>Classroom Applications of Clicker Technology</td>
<td>17</td>
</tr>
<tr>
<td>Mathematics self-efficacy</td>
<td>22</td>
</tr>
<tr>
<td>Mathematics anxiety</td>
<td>24</td>
</tr>
<tr>
<td>Potential effect of clickers on the relationship between math self-efficacy and math anxiety</td>
<td>27</td>
</tr>
<tr>
<td>Significance of the Present Study</td>
<td>28</td>
</tr>
<tr>
<td>CHAPTER 3. METHODOLOGY</td>
<td>30</td>
</tr>
<tr>
<td>Research Questions</td>
<td>30</td>
</tr>
<tr>
<td>Research Design – Mixed Methods</td>
<td>31</td>
</tr>
<tr>
<td>Site and participants</td>
<td>34</td>
</tr>
<tr>
<td>Research site</td>
<td>34</td>
</tr>
<tr>
<td>Participants – full sample</td>
<td>35</td>
</tr>
<tr>
<td>Participants – interview subsample</td>
<td>36</td>
</tr>
<tr>
<td>Instructor</td>
<td>38</td>
</tr>
<tr>
<td>Instruments</td>
<td>39</td>
</tr>
<tr>
<td>Surveys</td>
<td>39</td>
</tr>
<tr>
<td>Interviews</td>
<td>42</td>
</tr>
<tr>
<td>Data collection</td>
<td>43</td>
</tr>
<tr>
<td>Data analysis</td>
<td>49</td>
</tr>
</tbody>
</table>
CHAPTER 4. RESULTS ................................................................. 52

Research Question 1: Correlation between Math Anxiety and Math Self-efficacy,
  Relationship to Demographic Characteristics .................................................. 54
  Math anxiety and self-efficacy levels at beginning and end of semester .......... 54
  Change in math anxiety and math self-efficacy during the semester .......... 55
  Effect of demographic characteristics ............................................................. 56

Research Question 2: Correlations between Student Achievement (Grades) and Math
  Anxiety (MAS Scores), Student Achievement (Grades) and Math Self-efficacy
  (MSES Scores), Effect of Demographic Characteristics ..................................... 59
  Effect of demographic characteristics ............................................................. 60
  Math anxiety, math self-efficacy, and student perceptions of calculus course .... 60
  Comparison of initial MAS and MSES scores between students who completed
    both surveys versus students who only completed first survey ................. 61
  Student perceptions of clicker use ................................................................. 63
  Interview participants’ math anxiety and self-efficacy .................................... 63

Research Question 3: Student Perceptions of Effect of Clickers on Math Anxiety,
  Math Self-efficacy, and Achievement; Change in Perceptions during Semester;
  Differences between Students with Low and High Initial Math Anxiety Levels ... 66
  Effect of clickers on mathematics anxiety ....................................................... 66
  Effect of clicker activities on mathematics self-efficacy .................................. 68
  Immediate feedback provided by clickers ....................................................... 69
  Anonymous responses to clicker questions .................................................... 71
  Most beneficial aspects of clicker activities .................................................. 72
  Effect of clickers on attendance in the calculus course ................................... 74
  Effect of clickers on achievement in mathematics .......................................... 75
  Pressure to respond correctly to clicker questions ......................................... 77
  Differences between classes with clickers and traditional lectures ................ 79
  Effect of clickers on enjoyment of the calculus course ................................... 81
  Effect of clickers on mathematical thought processes ..................................... 82
  Instructor’s technique when using clickers ..................................................... 84
  Effect of clickers on attitude toward learning mathematics ............................ 85
  Perspectives on multiple choice format ......................................................... 87
  Clicker metaphors ............................................................................................ 88
  Additional perspectives on clickers (instructor) .............................................. 89
  End of interview comments (clickers) ............................................................. 90

Research Question 4: Student Perceptions of Relationships among Math Anxiety,
  Math Self-efficacy, and Achievement; Change in perceptions during semester;
  Differences between Students with Low and High Initial Math Anxiety Levels ... 90
  Mathematics anxiety ........................................................................................ 91
  Mathematics self-efficacy ................................................................................. 92
  Effect of math anxiety on achievement in mathematics ................................... 94
  Student perspectives on the instructor’s teaching style .................................... 96
  General effects of technology on college/university math instruction ............. 97
  Additional perspectives (instructor) ................................................................. 98
CHAPTER 5. DISCUSSION ......................................................................................................... 100
  Significance of the Study ..................................................................................................... 101
  Conclusions .......................................................................................................................... 101
  
  Current results confirmed relationships among math anxiety, mathematics self-efficacy, and math achievement .................................................................................. 102
  Use of clickers can facilitate desired learning outcomes ...................................................... 104
  A lack of mathematics anxiety may interfere with motivation and math achievement in some situations .............................................................................................................. 107
  Limitations ............................................................................................................................ 108
  Proposed Mechanisms .......................................................................................................... 110
  Implications for Teaching ...................................................................................................... 112
  Implications for Future Research .......................................................................................... 114
  Conclusion ............................................................................................................................. 116

APPENDIX A. INSTITUTIONAL REVIEW BOARD APPROVAL ................................................. 118
APPENDIX B. MAS INSTRUMENT AND PERMISSION EMAIL ............................................. 119
APPENDIX C. MSES SAMPLE ITEMS AND LICENSE .............................................................. 123
APPENDIX D. SURVEY INSTRUMENTS (PRE AND POST) ..................................................... 126
APPENDIX E. INTERVIEW AND CLASSROOM OBSERVATION PROTOCOLS .................... 130
APPENDIX F. CODING THEMES AND MATRICES ................................................................. 143
REFERENCES .......................................................................................................................... 151
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1.</td>
<td>Batchelor framework relating clicker use to math anxiety, self-efficacy, and achievement</td>
<td>6</td>
</tr>
<tr>
<td>Figure 2.1.</td>
<td>Proposed mechanisms relating clicker use to variables</td>
<td>16</td>
</tr>
<tr>
<td>Figure 4.1.</td>
<td>Student responses to questions about clicker use</td>
<td>64</td>
</tr>
<tr>
<td>Figure 4.2.</td>
<td>Mathematics anxiety scale scores for interview participants</td>
<td>65</td>
</tr>
<tr>
<td>Figure 4.3.</td>
<td>Mathematics self-efficacy scale scores for interview participants</td>
<td>65</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 3.1</td>
<td>Demographic data</td>
<td>38</td>
</tr>
<tr>
<td>Table 3.2</td>
<td>Six points of data collection</td>
<td>46</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Descriptive statistics</td>
<td>53</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Dependent variables by race/ethnicity</td>
<td>58</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Student responses to end-of-semester questions</td>
<td>62</td>
</tr>
</tbody>
</table>
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ABSTRACT

Many large lecture classes at undergraduate institutions have started to utilize technology to engage students. A mixed methods design was used in this dissertation research to build a comprehensive understanding of the statistical relationships among mathematics anxiety, math self-efficacy, and achievement in mathematics among students in a large lecture, undergraduate calculus class taught using clickers. The purpose of this study was to develop an understanding of the statistical relationships and of the students’ experiences and perspectives on the relationships among mathematics self-efficacy, math anxiety, and achievement, along with the effect of clicker use on these variables, with attention given to changes in student perceptions during the semester. Statistical analysis was conducted utilizing quantitative survey data, and qualitative methods were used to analyze student interview data. Pairwise statistical relationships identified in previous research were confirmed among math anxiety, mathematics self-efficacy, and achievement in mathematics. Findings also revealed the potential for clickers to help promote desired learning outcomes when used effectively by students and instructors. Future research on the effect of clicker use in other types of mathematics courses besides calculus, in classes with students representing a more diverse range of racial/ethnic backgrounds, and with smaller class sizes will help build on the knowledge gained from this study.
CHAPTER 1. INTRODUCTION

Mathematics instruction is a high priority in the United States educational system because math skills function as a gatekeeper to college and career opportunities (Bleyer, Pedersen, & Elmore, 1981; Booth & Newton, 2012; Buckley, 2010; Reyes, 2010; Sells, 1981). Sells (1980) described mathematical proficiency as a “critical filter” that determines what opportunities will be available to an individual (p. 340). According to Buckley (2010), mathematical understanding is necessary for economic and democratic participation in our society. Bleyer et al. (1981) cautioned that students who avoid taking advanced math courses in high school are less likely to succeed in college and have limited career options. Sells (1981) claimed the filtering process based on math ability begins in elementary school, stating that a student’s failure to master arithmetic skills in the elementary grades creates a major barrier to career opportunities as an adult. At the high school level, Algebra 1 is regarded as a gatekeeper course that determines whether students pursue advanced math courses (Booth & Newton, 2012). Likewise, college algebra is considered a gatekeeper course for undergraduate students (Reyes, 2010).

Educational researchers and policymakers have expressed great concern about mathematics achievement in the United States based on comparisons with other countries (Kankaraš & Moors, 2014; Täht & Must, 2013; Tienken, 2013; Turgut, 2013; Zhao, 2005). Results from the Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) suggest that numerous countries are outperforming the United States in mathematics (Täht & Must, 2013; Zhao, 2005). In 2010, Secretary of Education Arne Duncan stated, “Unfortunately, the 2009 PISA results show that
American students are poorly prepared to compete in today’s knowledge economy. President Obama has repeatedly warned that the nation that ‘…out-educates us today will out-compete us tomorrow’. And, the PISA results, to be brutally honest, revealed that a host of developed nations are out-educating us” (Tienken, 2013, p. 56).

A considerable amount of controversy has arisen regarding the comparability of results on international assessments such as PISA and TIMSS (Kankaraš & Moors, 2014; Turgut, 2013; Zhao, 2005). Kankaraš and Moors (2014) claimed that the PISA tests given in different countries may not be equivalent due to cultural and linguistic differences. They cautioned readers that many factors may influence test results, including translation and students’ differing familiarity with the format of the assessments. In addition, cultural bias may be present in the content of specific test items. The authors concluded that the comparison of test results across countries is highly questionable. Täht and Must (2013) conducted a factor analysis based on the PISA 2006 data. They concluded that comparisons of different countries’ PISA scores are unjustified. Tienken (2013) claimed every nation that outperformed the United States on the PISA 2009 mathematics assessment had significantly lower rates of childhood poverty in comparison with the U.S. He asserted that U.S. students score higher than any other country after controlling for the national poverty rate. The PISA and TIMSS results have called attention to the need to increase mathematics achievement in the United States. In the following section, I discuss factors that may affect students’ math achievement.

**Major Topics and Definitions**

Educational researchers have identified several variables that may influence students’ achievement in mathematics (Betz, 1978; Cooper & Robinson, 1991; Hembree, 1990; Pajares
& Urdan, 1996). Mathematics anxiety and math self-efficacy are two such variables. 

*Mathematics anxiety* is defined as “feelings of tension and anxiety that interfere with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations” (Richardson & Suinn, 1972, p. 551). A strong negative correlation exists between math anxiety and achievement in mathematics (Adams & Holcomb, 1986; Betz, 1978; May, 2009; Suinn & Winston, 2003). That is, students with higher levels of mathematics anxiety tend to earn lower grades and test scores in mathematics. Researchers have distinguished between the cognitive and affective components of math anxiety (McLeod, 1988; Orton, 2004). The cognitive component pertains to thoughts and worries, while the affective component involves feelings and emotions.

A related variable is *mathematics self-efficacy*, defined as “a situational or problem-specific assessment of an individual’s confidence in her or his ability to successfully perform or accomplish a particular task or problem” (Hackett & Betz, 1989, p. 262). Researchers have demonstrated a strong negative correlation between mathematics anxiety and math self-efficacy (Ashcraft, 2002; Betz & Hackett, 1983; Pajares & Urdan, 1996). In other words, students who lack confidence in their own mathematical ability tend to have higher levels of math anxiety. Not surprisingly, mathematics self-efficacy is positively correlated with achievement in mathematics (Cooper & Robinson, 1991; Hoffman, 2010; Pajares & Kranzler, 1995).

Considering the demonstrated relationships among math anxiety, mathematics self-efficacy, and math achievement, it seems reasonable that interventions to reduce math anxiety and increase mathematics self-efficacy may represent a viable strategy to improve
achievement in mathematics. Educational researchers and psychologists have developed numerous interventions to help treat math anxiety (Hembree, 1990; Mitchell, 1987; Tobias & Weissbrod, 1980). Clinical interventions include systematic desensitization, cognitive restructuring, and relaxation techniques (Mitchell, 1987; Richardson & Suinn, 1972).

Classroom interventions represent another potential avenue to help reduce mathematics anxiety and increase students’ math self-efficacy (Hembree, 1990). Tobias and Weissbrod (1980) recommended changing the classroom environment from an emphasis on competition to a focus on trust and cooperation. Recent forms of instructional technology may also have the potential to help increase student achievement by reducing math anxiety and increasing math self-efficacy (Cline, 2006; Fies & Marshall, 2006; Titman & Lancaster, 2011). The present study focused on one form of technology, clickers, and investigated the relationships among clicker use and other variables such as math anxiety, mathematics self-efficacy, and achievement in mathematics.

**Problem Statement**

Given the importance of strong mathematical skills and the concerns about math achievement in the United States, it is imperative that we identify factors that may be inhibiting students’ math achievement and search for interventions to help improve achievement in mathematics. Clickers are a relatively new instructional tool that some mathematics instructors use in their teaching. Clickers are handheld units that transmit students’ responses to questions, which are often presented in a multiple-choice format (Lim, 2011). Most models of clickers include a keypad with the digits 0 through 9, and some models include a display screen.
Clickers provide an opportunity to increase student participation in mathematics courses, especially when a class is taught in a large lecture format (Bruff, 2009; Cline, 2006; Lock, 2011; Strasser, 2010; Woelk, 2008). However, little is known about the relationships between clicker use and other variables such as mathematics anxiety and achievement in mathematics. There is a clear need for systematic research to investigate these relationships. A previous quantitative study suggested that an inverse relationship may exist between clicker use and mathematics anxiety among students enrolled in large lecture math courses (Batchelor, 2015). However, additional research is needed to investigate the relationships among clicker use, math anxiety, mathematics self-efficacy and math achievement, and to provide an understanding of the mechanisms that underlie these relationships.

**Conceptual Framework**

Teddlie and Tashakkori (2009) defined a conceptual framework as a “consistent and comprehensive framework emerging from an inductive integration of previous literature, theories, and other pertinent information” (p. 39). They claimed that a conceptual framework has high heuristic value if it has the potential to generate questions or ideas that may lead to informative and valuable research studies. Figure 1.1 depicts a visual diagram of the conceptual framework for the present study. I developed the conceptual framework with the goal of relating the variables that are most relevant to the research questions. I began by creating a detailed concept map connecting nearly 100 variables and concepts identified through an extensive review of the literature. I gradually refined the framework in several iterations to include only the variables and concepts I believe to be most relevant to the
research questions. The directed arrows represent anticipated relationships between specific components of the framework based on the literature review.

Figure 1.1. Batchelor framework relating clicker use to math anxiety, self-efficacy, and achievement

The conceptual framework for this study is comprised of five primary components: clickers, pedagogical changes that accompany clicker use, mathematics self-efficacy, math anxiety, and achievement in mathematics. The arrows in the diagram represent hypothesized causal or influential relationships between components. For example, higher levels of math anxiety are believed to contribute to decreased achievement in mathematics. The conceptual framework is discussed in greater detail in Chapter 2.

Research Questions

The present study investigated four specific aspects of the conceptual framework using quantitative and qualitative data collection and analysis procedures. I developed the following list of research questions with the goal of addressing the most important topics and connections represented in the conceptual framework.
1. What is the correlation between mathematics anxiety and math self-efficacy among students enrolled in an undergraduate calculus course involving the use of clickers? How is the correlation affected by the students’ demographic characteristics?

2. How does student achievement, as measured by students’ final course grades, correlate with math anxiety and mathematics self-efficacy in a calculus course involving the use of clickers? How are the correlations affected by the students’ demographic characteristics?

3. How do students perceive and experience the effect of clickers on their levels of mathematics anxiety and math self-efficacy and on their success in learning calculus? How do the students’ perceptions change over the course of the semester? How do the perceptions differ between students with low and high initial math anxiety levels?

4. How do students perceive and experience the relationships among mathematics self-efficacy, math anxiety, and achievement in a calculus class where clickers are used? How do the students’ perceptions change during the semester? How do the perceptions differ between students with high and low initial levels of mathematics anxiety?

**Purpose Statement and Overview**

The purpose of my dissertation research was to use qualitative and quantitative methods to gain a deeper understanding of the relationships among clicker use, math anxiety, mathematics self-efficacy, and math achievement and the mechanisms that underlie these relationships. I tested the validity of each proposed mechanism based on qualitative and quantitative data. I believe the results of my study will provide a context for other researchers who wish to study the relationships between clicker use, mathematics anxiety,
math self-efficacy, and achievement in mathematics. Future studies may include research involving the use of clickers as a direct intervention to reduce math anxiety, increase mathematics self-efficacy, and improve students’ math achievement.

The participants in my study were undergraduate students enrolled in a large lecture calculus course at a large Midwestern university during the Fall 2015 semester. The instructor taught the class using clickers. Students who chose to participate took two surveys, one near the beginning of the semester and the other near the end of the course. Both surveys included all items on the Mathematics Anxiety Scale (Betz, 1978) and the Mathematics Self-Efficacy Scale (Betz & Hackett, 1993). A subsample of four students was selected to participate in four interviews each and complete the Mathematics Anxiety Scale and Mathematics Self-Efficacy Scale four additional times. I interviewed each student in the subsample four times during the semester. All interviews were audio recorded. Statistical software was used to analyze the quantitative survey results, and qualitative analysis procedures were used to analyze the interview transcripts. Chapter 3 contains a thorough summary of the study methodology.

**Significance of the Study**

With the exception of one study (Batchelor, 2015), I was not aware of any previous research that focused specifically on the relationship between clicker use and mathematics anxiety. I am hopeful that the present study will help to fill a gap in the literature and provide substantive data regarding the relationship between clicker use and math anxiety among students enrolled in undergraduate courses. Finally, I believe this study has the potential to inform future research, potentially including studies involving clicker use as a
direct intervention to reduce math anxiety and increase students’ mathematics self-efficacy and achievement.

**Organization of the Dissertation**

This dissertation was organized into five chapters, including the present introduction chapter. Chapter 2 provides a review of the literature on classroom use of clicker technology, mathematics self-efficacy, and math anxiety and the relationships among these variables. The second chapter also proposes three potential mechanisms through which the use of clickers may affect students’ mathematics anxiety, math self-efficacy, and achievement in mathematics. Chapter 3 begins with a discussion of my rationale for choosing a mixed methods research design, followed by a detailed summary of the qualitative and quantitative data collection and analysis procedures I used in this dissertation study. Chapter 4 provides the results of the data analysis, including the quantitative analysis of survey responses and the qualitative analysis of the student interview transcripts. The final chapter provides a discussion of the results, and implications for practice and future research.
CHAPTER 2. LITERATURE REVIEW

Educational researchers have been concerned about mathematics anxiety since the 1950s (Dreger & Aiken, 1957; Gough, 1954). Gough (1954) warned educators that “mathemaphobia” was a “disease” requiring a “concerted effort to educate the public against its insidious attacks” (p. 290). Dreger and Aiken (1957) described “number anxiety” as a “syndrome of emotional reactions to arithmetic and mathematics” (p. 344). Classroom interventions, including the use of clickers, may have the potential to help students reduce their levels of math anxiety (Caldwell, 2007; Cline, 2006; D’Inverno, Davis, & White, 2003; Lim, 2011; Robinson & King, 2009).

Bandura’s (1986) theory of self-efficacy provides a theoretical foundation that may help explain the relationship between clicker use and math anxiety (Hackett & Betz, 1989; Pajares, 1996). Self-efficacy theory has become one of the leading theories of human action and has inspired a tremendous amount of research over the past 30 years (Bandalos, Yates, & Thorndike-Christ, 1995; Cooper & Robinson, 1991; Hackett & Betz, 1989; Jain & Dowson, 2009; Lent, Lopez, & Bieschke, 1991; Matsui, Matsui, & Ohnishi, 1990; Pajares & Kranzler, 1995; Rottschaef er, 1991; Usher & Pajares, 2008). Bandura (1986) defined self-efficacy as “people’s judgments of their capabilities to organize and execute courses of action required to attain designated types of performances” (p. 391). An important feature of the definition is that self-efficacy refers to an individual’s perception of her/his ability to accomplish a given task, as opposed to the person’s actual skills or ability to succeed with the task (Bandura, 1986; Usher & Pajares, 2008). According to Bandura (1986), anxiety is caused by “perceived ineffectiveness to cope with potentially aversive events” (p. 440).
Bandura’s (1986) theory asserts that a person’s self-efficacy beliefs come from four primary sources: mastery experiences, vicarious experience, verbal and social persuasions, and emotional and psychological states (Bandura, 1982; Rottschaefer, 1991). Mastery experiences represent a person’s interpretation of her/his previous achievements, while vicarious experience refers to observations of other people’s achievements or failures (Bandura, 1977; Usher & Pajares, 2008). Bandura (1982) claimed that encouragement and discouragement received from parents, teachers, and peers influence an individual’s self-efficacy beliefs. These verbal and social persuasions may play a significant role in the development of a person’s perceived self-efficacy (Bandura, 1977; Usher & Pajares, 2008). Finally, emotional and physiological states such as anxiety and fatigue are believed to affect the formation of self-efficacy beliefs (Bandura, 1986). Self-efficacy may play a major role in the choices people make, especially regarding college majors and career paths (Betz & Hackett, 1983; Cooper & Robinson, 1991; Matsui et al., 1990).

Each of Bandura’s (1986) four hypothesized sources of self-efficacy beliefs is relevant to the use of clickers in a large lecture calculus class. Mastery experiences occur when a student votes for a response to a clicker question, learns whether the response is correct, and interprets the significance of the correct or incorrect response. A student has vicarious experiences when he or she learns what percentage of the class voted for the correct answer to a question and sees the visible reactions of other students when the correct response is revealed. Students experience verbal and social persuasions when an instructor comments on the distribution of correct and incorrect responses to a question or when other students discuss the difficulty level of a question.
The emotional and physiological states experienced by students in a clicker class may include a student’s anxiety over her/his ability to choose the correct answer to a question, along with euphoria or disappointment when a student learns whether he or she voted for the correct response. I kept the four proposed sources of self-efficacy beliefs in mind when formulating the proposed mechanisms underlying the relationships among the variables in the conceptual framework and while developing the interview questions for the study. A vast collection of research exists on the topic of mathematics anxiety, and many recent studies have explored the effects of using clickers in math classes (Akin & Kurbanoglu, 2011; Batchelor, 2015; Betz, 1978; Cline, 2006; Crouch & Mazur, 2001; Gibson, 2011; Hoffman, 2010; Lim, 2011; Mitchell, 1987; Popelka, 2010; Suinn & Winston, 2003; Tobias, 1993; Woelk, 2008). However, the research bases regarding math anxiety and clicker use in math courses are largely independent of each other. With the exception of one previous study (Batchelor, 2015), when I conducted this research I was unable to identify any previous study that explored the relationship between clicker use and mathematics anxiety.

**Conceptual Framework**

The conceptual framework for the present study is summarized in Figure 1.1 as shown in Chapter 1. The primary components of the conceptual framework are clickers, pedagogical changes, mathematics self-efficacy, math anxiety, and achievement in mathematics. The conceptual framework was developed to include only the most important components and relationships that appear to be significant in the proposed mechanisms relating clickers, math anxiety, and achievement in mathematics. In the following sections, I discuss the paths represented in the framework and the literature relevant to each path. Then,
using Bandura’s (1986) theory of self-efficacy as a foundation, I consider three potential mechanisms that may explain how clicker use affects the other variables in the conceptual framework.

Some components of the conceptual framework are believed to affect or influence others. The hypothesized causal or influential relationships are denoted by arrows in Figure 1.1. Starting in the upper-left corner, the use of clickers is hypothesized to influence students’ mathematics self-efficacy and math anxiety, as well as the pedagogical decisions of teachers. The pedagogical changes that accompany clicker use may directly affect students’ mathematics self-efficacy, math anxiety, and/or achievement in mathematics. Clicker technology and the accompanying pedagogical shifts have been found to influence students’ levels of mathematics self-efficacy (Bode, Drane, Kolikant, & Schuller, 2009; Vaterlaus, Beckert, Fauth, & Teemant, 2012).

Researchers have established a strong negative correlation between mathematics self-efficacy and math anxiety (Cooper & Robinson, 1991). That is, students with higher levels of math anxiety tend to have less confidence in their own mathematical ability. The presence of a strong negative correlation between mathematics anxiety and math self-efficacy does not prove that one variable causes a change in the other. However, the present study hypothesized that math anxiety and mathematics self-efficacy mutually influence each other. It seems plausible that students who develop a perception of having poor math skills will then experience higher levels of math anxiety. Conversely, students who experience high mathematics anxiety may begin to doubt their math ability. The bi-directional arrow between mathematics anxiety and math self-efficacy in Figure 1.1 represents the hypothesized mutual influence between the variables.
A strong positive correlation exists between math self-efficacy and achievement in mathematics (Hackett & Betz, 1989; Pajares & Kranzler, 1995). In other words, students with higher levels of math self-efficacy tend to earn higher grades and test scores in mathematics. While the positive correlation between mathematics self-efficacy and math achievement does not prove causation, the present study hypothesizes that the variables mutually influence each other. This hypothesized mutual influence is represented in Figure 1.1 by the bi-directional arrow between math self-efficacy and achievement in mathematics.

Finally, math anxiety is negatively correlated with achievement in mathematics (Dew, Galassi, & Galassi, 1984). In a meta-analysis of 151 studies, Hembree (1990) concluded that math anxiety is a likely cause of poor mathematics performance. The current study hypothesized that math achievement and mathematics anxiety have a mutual influence on each other, denoted by the bi-directional arrow between the variables in Figure 1.1. Students who earn poor grades and test scores in mathematics may become more anxious and perceive themselves as not being good at math, causing them to “give up” or put less effort into their math courses, resulting in continued poor math achievement and low math self-efficacy.

When discussing the elements of the conceptual framework, it is important to be aware of how specific components of the framework are linked to theory. Mathematics self-efficacy is a form of self-efficacy, which is a theory that Bandura (1986) proposed to explain people’s perceptions of their competency within specific domains. According to Bandura’s theory, anxiety is caused by an individual’s perceived inefficacy to handle situations that could potentially be threatening or aversive. Bandura’s theory asserts that individuals with lower levels of self-efficacy are less likely to persevere within a given domain, which typically results in decreased achievement within that domain. In particular, the theory
implies that people with high levels of mathematics anxiety are likely to lack math self-efficacy, causing them to experience decreased math achievement.

Clickers are an instructional tool, but clicker use is not a theory. This is an important distinction; it is critical to understand how theory informs the conceptual framework. The use of clickers in a mathematics classroom may create conditions conducive to increased math self-efficacy and lower levels of mathematics anxiety. Previous studies have found that clickers help to promote student engagement and create a more comfortable learning environment for students (Cline, 2006; Popelka, 2010). The positive classroom conditions facilitated by clicker use may lead to decreased math anxiety and higher levels of mathematics self-efficacy. According to Bandura’s (1986) theory of self-efficacy, if clickers contribute to increased math self-efficacy and decreased math anxiety, an increase in students’ math achievement will be a likely consequence of the clicker use. Indeed, previous studies have shown a positive correlation between clicker use and achievement in mathematics (Lim, 2011; Strasser, 2010).

The current study proposed three potential mechanisms through which clicker use may affect calculus students’ mathematics anxiety, math self-efficacy, and achievement in mathematics. Figure 2.1 contains visual diagrams of the three proposed mechanisms. Mechanism 1 asserts that the immediate feedback provided by clicker use facilitates mastery experiences that help students feel more confident in their math ability, thus leading to increased math self-efficacy and decreased mathematics anxiety. Consistent with Bandura’s (1986) self-efficacy theory, increased math achievement would then occur. In addition, the immediate feedback provides vicarious experience when students view the histograms
showing how well other students performed and see how classmates react after the instructor reveals the correct response.

According to Mechanism 2, clicker use causes students to feel pressured to select the correct answer to each clicker question and worry about the effect of the responses on their grades. Students who are worried about choosing the correct response may also be negatively impacted by verbal and social persuasions if they answer a question incorrectly and the instructor or classmates state that the question was relatively easy. The resulting
negative emotional and physiological states are hypothesized to cause an increase in math anxiety and a decrease in mathematics self-efficacy, leading to decreased achievement in mathematics.

Mechanism 3 claims that clicker use will lead to increased classroom participation and student engagement, making the lectures more enjoyable and comfortable for students and increasing the likelihood that they will attend class regularly. The increased attendance and positive emotional and physiological states will result in an increase in math self-efficacy and a decrease in mathematics anxiety, and students will likely earn higher grades in the course in accordance with Bandura’s (1986) theory of self-efficacy.

The present study investigated the validity of each of the proposed mechanisms. In the following sections, I review the literature on clickers, mathematics self-efficacy, and math anxiety and consider the potential of clickers to help reduce students’ math anxiety and improve achievement in mathematics.

**Classroom Applications of Clicker Technology**

Technology companies, along with many educational researchers, have claimed that clicker use can help improve the practice of teaching mathematics at the college level (Bode et al., 2009; Cline, 2006; Lock, 2011; Retkute, 2009; Woelk, 2008). Lim (2011) defined clickers as “handheld units in a personal response system that can transmit, record, and display students’ responses to questions (typically multiple-choice or true-false)” (p. 1,082). Alternate names for clickers include polling devices, keypads, handsets, and zappers (Butler, Pyzdrowski, Walker, & Yoho, 2010; Caldwell, 2007; Popelka, 2010). Clicker software systems also have various names, including classroom voting systems, electronic voting
systems, and personal response systems (Bode et al., 2009; Butler et al., 2010; Cline, 2006; Kolikant, Drane, & Calkins, 2010; Retkute, 2009; Robinson & King, 2009). Common brand names of clickers include InterWrite PRS, TurningPoint, and EduCue (Cline, 2006; Roth, 2012; Titman & Lancaster, 2011).

Typical features of clickers include a keypad with the numbers 0 through 9 (generally arranged like a telephone keypad) and identification numbers for tracking purposes (Butler et al., 2010; Retkute, 2009). Some models include a display screen or a confidence level feature enabling students to communicate how confident they feel about their responses (Bode et al., 2009; Kolikant et al., 2010). The most common formats for clicker questions are multiple-choice, true/false, and questions with numerical answers that students enter on the keypads (Cline, 2006). Although many clicker questions involve skills, clickers can be used effectively to respond to conceptual questions (Bode et al., 2009; Cline, 2006; Sharp, 2011; Woelk, 2008). Several collections of clicker questions are available to math instructors online, including ConcepTests, the Cornell GoodQuestions Project, and Project Math QUEST (Cline, Parker, Zullo, & Stewart, 2013; Gibson, 2011; Lock, 2011; Lucas, 2009; Roth, 2012).

Mathematics instructors need to adjust their pedagogical strategies when they begin using clickers in the classroom in order to accommodate the technology (Elicker & McConnell, 2011; Gray, Owens, Liang, & Steer, 2012; Kolikant et al., 2010; Larsgaard, 2011; Lim, 2011; Lucas, 2009; McGivney & McGivney-Burelle, 2011; Shaffer & Collura, 2009; Sun, 2014; Titman & Lancaster, 2011). According to Titman and Lancaster (2011), the primary benefits of using clickers “stem from the pedagogical shift from passive to active learning” encouraged by the technology (p. 10). Several authors have related clicker use to
Eric Mazur’s Peer Instruction (PI) framework (Crouch & Mazur, 2001; Gray et al., 2012; Lucas, 2009; McGivney & McGivney-Burelle, 2011).

An instructor using the Peer Instruction method with clickers begins by presenting a clicker question and having students work individually to answer the question. Students then vote using clickers, and the instructor presents the resulting histogram. Finally, students work on the question in pairs or small groups and vote a second time (Bruff, 2009; Lucas, 2009). An instructor may ask clicker questions before or after introducing a new concept (Bode et al., 2009; Bruff, 2009). According to Cline et al. (2013), the success of a clicker question in promoting student discussion “depends critically on when the question is asked, in addition to the content of the question itself” (p. 72).

Several aspects of clicker use may be beneficial to students and instructors in a large lecture mathematics class (Bruff, 2009; Popelka, 2010; Sharp, 2011). Numerous authors have asserted that clickers promote student engagement and help instructors facilitate an active learning environment (Bode et al., 2009; Bruff, 2009; Caldwell, 2007; Cline, 2006; Gibson, 2011; Lock, 2011; Retkute, 2009; Strasser, 2010; Sun, 2014; Woelk, 2008). Clicker software programs provide immediate feedback to instructors and students (Cline, Zullo, & Parker, 2008; McGivney & McGivney-Burelle, 2011; Serros, Hofacker, & Ernie, 2011). Students can respond to clicker questions without classmates knowing what answer they choose, which may help promote a comfortable learning environment (Elicker & McConnell, 2011; Lim, 2011; Popelka, 2010; Sharp, 2011; Titman & Lancaster, 2011). The software also provides instructors an efficient means of monitoring attendance (Fies & Marshall, 2006; Shapiro, 2009; Strasser, 2010).
As discussed in the previous section, the positive classroom conditions facilitated by clicker use may have the potential to help increase students’ math self-efficacy and decrease mathematics anxiety. If this is the case, Bandura’s (1986) self-efficacy theory would assert that increased math achievement is a likely consequence of clicker use. This conclusion is consistent with the findings of several studies that mathematics test scores and content knowledge improve when students use clickers in class (Gibson, 2011; Kolikant et al., 2010; Lim, 2011; Retkute, 2009; Shaffer & Collura, 2009; Strasser, 2010).

Clicker questions can give students an opportunity to work in small groups and discuss solutions both before and after voting (Caldwell, 2007; Kolikant et al., 2010). Students frequently report that they enjoy mathematics courses more when they use clickers (Bode et al., 2009; Cline, 2006; D’Inverno et al., 2003; Sharp, 2011; Vaterlaus et al., 2012). Clickers may serve as a formative assessment tool when instructors consider which students choose specific responses and identify patterns in student responses (Butler et al., 2010; Gray et al., 2012; Popelka, 2010; Titman & Lancaster, 2011). Finally, clicker software may assist in identifying student misconceptions and facilitating error analysis (D’Inverno et al., 2003; Robinson & King, 2009; Sharp, 2011).

Despite the benefits of using clickers in the classroom, clicker use has some drawbacks and limitations (Caldwell, 2007; Fies & Marshall, 2006; Gibson, 2011; Strasser, 2010). A clicker system (including clickers and software) may cost thousands of dollars, depending on the number of students in a class (Bode et al., 2009; McGivney & McGivney-Burelle, 2011). Time constraints represent another drawback associated with the use of clickers (D’Inverno et al., 2003; Gibson, 2011; Lock, 2011; Robinson & King, 2009). Instructors must spend a considerable amount of time learning to use the software and
preparing clicker questions, and class time is required to start the computer and projector and sign in the individual clickers (Cline, 2006; Kolikant et al., 2010). According to Sharp (2011), “The preparation done behind the scenes is critical if one is to have any success using the clickers” (p. 122).

Clicker software systems place limitations on the question formats an instructor may use (Cline, 2006; D’Inverno et al., 2003; Sharp, 2011). Researchers have identified some potential issues with grading clicker responses (Bruff, 2009; Caldwell, 2007; Popelka, 2010). While grading clicker responses may encourage students to take the questions seriously, this practice may also increase the pressure on students to obtain and vote for the correct response within the time allowed (Bruff, 2009). Caldwell (2007) encourages instructors to provide updates on students’ clicker grades and drop some of the lowest scores to reduce the discomfort that students experience. The added pressure to vote for the correct response could potentially increase students’ math anxiety and decrease their mathematics self-efficacy. According to Bandura’s (1986) theory of self-efficacy, decreased achievement in mathematics would then be a likely consequence. The present study investigated students’ perceptions regarding the amount of pressure they feel to choose the correct answer to each clicker question.

Some students may enjoy using clickers in the classroom whereas others may not find the technology helpful (Butler et al., 2010; Caldwell, 2007). Kolikant et al. (2010) remarked that students sometimes resist change in the “unwritten rules of the game” when an instructor introduces clickers in a course (p. 129). Finally, as with all forms of instructional technology, there is no guarantee that the introduction of clickers in a classroom will improve learning outcomes (Brosnan & Goodison, 2010; Gibson, 2011; Kolikant et al., 2010; Lim,

**Mathematics self-efficacy**

Hackett and Betz (1989) defined mathematics self-efficacy as “a situational or problem-specific assessment of an individual’s confidence in her or his ability to successfully perform or accomplish a particular task or problem” (p. 262). Male students tend to have higher levels of math self-efficacy in comparison with females (Betz & Hackett, 1983; Dowling, 1978; Lent et al., 1991; Matsui et al., 1990). However, in a study of middle school students, Pajares (1996) did not find a statistically significant difference in mathematics self-efficacy between gifted boys and girls. Research has also indicated that an instructor’s pedagogical choices may have a significant impact on students’ self-efficacy in mathematics (Hackett, 1985; Pajares & Kranzler, 1995). Students with lower levels of mathematics self-efficacy tend to avoid career paths and college majors related to mathematics (Betz & Hackett, 1983; Dowling, 1978; Hackett, 1985; Lent et al., 1991; Matsui et al., 1990).

A strong negative correlation has been demonstrated between mathematics anxiety and math self-efficacy (Akin & Kurbanoglu, 2011; Bandalos et al., 1995; Clute, 1984; Cooper & Robinson, 1991; Hackett, 1985; Hoffman, 2010; Jameson, 2010; Lyons & Beilock, 2012; Matsui et al., 1990; May, 2009; Park, Ramirez, & Beilock, 2014; Usher, 2009). Pajares (1996) obtained zero-order correlations of –0.42 between math anxiety and achievement, –0.67 between math anxiety and math self-efficacy, and 0.60 between math self-efficacy and math achievement in his study involving gifted middle school students.
Jain and Dowson (2009) obtained a correlation of –0.43 between mathematics self-efficacy and math anxiety, while Akin and Kurbanoglu (2011) obtained a correlation of –0.49. In a study of mathematics problem-solving efficiency, Hoffman (2010) obtained a correlation of –0.48 between math self-efficacy and math anxiety. No previous studies known to the current researcher have established whether the negative correlation between mathematics anxiety and math self-efficacy holds in classes taught with clickers.

Students who are more confident in their mathematical ability tend to have lower levels of math anxiety. According to Jain and Dowson (2009), academic self-regulation techniques may help increase mathematics self-efficacy and decrease math anxiety. Akin and Kurbanoglu (2011) found that students with positive attitudes toward mathematics tend to be more confident in their math ability and have lower math anxiety levels. Betz and Hackett (1983) remarked that the observed negative correlation between mathematics anxiety and math self-efficacy is consistent with Bandura’s claim that self-efficacy and anxiety are inversely related.

Numerous researchers have found a significant positive correlation between mathematics self-efficacy and math achievement (Cooper & Robinson, 1991; Hackett & Betz, 1989; Hoffman, 2010; Lent, Lopez, & Bieschke, 1993; Pajares & Kranzler, 1995; Pajares, 1996; Siegel, Galassi, & Ware, 1985). It seems reasonable that mathematics anxiety may affect the relationship between math self-efficacy and achievement in mathematics since math anxiety is negatively correlated with both variables (Adams & Holcomb, 1986; Ashcraft, 2002; Betz, 1978; Hoffman, 2010; May, 2009; Suinn & Winston, 2003). An individual’s actual ability in mathematics may underlie the observed relationship between math achievement and self-efficacy (Cooper & Robinson, 1991; Pajares & Kranzler, 1995).
According to Pajares (1996), Bandura’s theory of self-efficacy is effective in explaining the positive correlation between math achievement and mathematics self-efficacy.

**Mathematics anxiety**

Richardson and Suinn (1972) defined *mathematics anxiety* as “feelings of tension and anxiety that interfere with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations” (p. 551). Alternately, Ashcraft (2002) defined math anxiety as “a feeling of tension, apprehension, or fear that interferes with math performance” (p. 181). Researchers have distinguished between the cognitive component (negative thoughts and worries regarding one’s own math ability) and the affective component (emotions and physiological reactions) of math anxiety (Dew, Galassi, & Galassi, 1983; Ho, Senturk, Lam, Zimmer, Hong, Okamoto, Chiu, Nakazawa, & Wang, 2000; Ma & Kishor, 1997; McLeod, 1988; Orton, 2004; Wigfield & Meece, 1988).

Experts have generally agreed that math anxiety involves multiple dimensions or factors (Dreger & Aiken, 1957; Resnick, Viehe, & Segal, 1982; Rounds & Hendel, 1980). Rounds and Hendel (1980) claimed there is “clear evidence” of two or more factors of math anxiety (p. 141), and identified two as “mathematics test anxiety” and “numerical anxiety” (p. 142). Resnick et al. (1982) added three additional factors of mathematics anxiety: “evaluation anxiety,” “arithmetic computation anxiety,” and “social responsibility anxiety” (p. 44). Math anxiety may also have a negative effect on working memory capacity and cognitive processing (Adams & Holcomb, 1986; Ashcraft, 2002; Bai, Wang, Pan, & Frey, 2009; Beilock & Willingham, 2014; Hoffman, 2010; Ramirez, Gunderson, Levine, & Beilock, 2013; Vukovic, Roberts, & Wright, 2013). Physical symptoms of mathematics
anxiety include stomachache, shortness of breath, perspiration, and muscle tension; mental symptoms include sensitivity to noise, negative self-talk, and an inability to concentrate (Jain & Dowson, 2009; Kitchens, 1995; Mitchell, 1987; Probert, 1983; Tobias, 1993).

Educational researchers have identified several factors as likely correlates of mathematics anxiety, although causation is much more difficult to establish (Adams & Holcomb, 1986; Betz, 1978; Clute, 1984; Hembree, 1990; Jain & Dowson, 2009; Pajares & Urdan, 1996; Rattan, Good, & Dweck, 2012; Resnick et al., 1982; Tobias & Weissbrod, 1980; Zaslavsky, 1994). Most scholars agree that math anxiety occurs more frequently and tends to be more severe among females than males (Bessant, 1995; Fennema & Sherman, 1977; Orton, 2004; Probert, 1983; Wigfield & Meece, 1988). On one hand, math anxiety occurs more often in older people than in younger individuals (Betz, 1978; Jain & Dowson, 2009). On the other hand, people who have taken more mathematics courses tend to have lower levels of math anxiety (Adams & Holcomb, 1986; Resnick et al., 1982; Rounds & Hendel, 1980).

A significant positive correlation exists between test anxiety and math anxiety (Ashcraft, 2002; Cassady, 2010; Dew et al., 1984; Hembree, 1990; Ho et al., 2000; Orton, 2004; Wigfield & Meece, 1988). Students with higher grades and test scores in mathematics tend to have lower levels of math anxiety (Bai et al., 2009; Ironsmith, Marva, Harju, & Eppler, 2003). College students with higher levels of math anxiety tend to be less willing to take advanced mathematics courses and choose math-related majors (Gough, 1954; Jain & Dowson, 2009; Jameson, 2010; Probert, 1983; Ramirez et al., 2013; Suinn & Winston, 2003). Students who restrict themselves to majors that are not math-related have fewer career options (Adams & Holcomb, 1986; Ashcraft, 2002; Dew et al., 1984; Pajares & Urdan,
Individuals who have had negative experiences with math courses in the past tend to have higher levels of math anxiety (Jain & Dowson, 2009; Jameson, 2010; Kogelman & Warren, 1978; Vukovic, Kieffer, Bailey, & Harari, 2013; Zaslavsky, 1994).

Several mathematics education scholars and practitioners have developed classroom interventions that instructors can use while teaching in order to help reduce students’ levels of math anxiety and increase mathematics self-efficacy (Beilock & Willingham, 2014; Hembree, 1990; Rattan et al., 2012; Tobias & Weissbrod, 1980). Tobias and Weissbrod (1980) suggested changing the classroom atmosphere from an emphasis on “tension and competition” to a focus on cooperation and trust (p. 67). The present study focused on clicker technology and explored the relationships among clicker use, mathematics anxiety, math self-efficacy, and achievement in mathematics. Clickers and the pedagogical changes that accompany clicker use may help students participate more actively in class and feel less intimidated by math courses.

Researchers have developed several instruments to measure mathematics anxiety. Two leading instruments are Betz’s (1978) Mathematics Anxiety Scale (MAS) and Richardson and Suinn’s (1972) Mathematics Anxiety Rating Scale (MARS). The Mathematics Anxiety Scale, which was used in the present study, consists of ten items scored on a five-point Likert scale. The Mathematics Anxiety Rating Scale (MARS) is a survey instrument containing 98 items. Suinn and Winston (2003) published a shorter, 30-item version of the MARS and verified the comparability of the abridged version to the original instrument in terms of validity and reliability. Although the MAS and MARS are the most frequently used instruments for measuring mathematics anxiety, they are not the only such measures. Wigfield and Meece (1988) developed the Math Anxiety Questionnaire (MAQ),
an eleven-item survey instrument. Seven of the items on the MAQ address the affective dimension of math anxiety, while the other four items relate to the cognitive dimension.

**Potential effect of clickers on the relationship between math self-efficacy and math anxiety**

An instructor’s pedagogical choices are relevant both to mathematics anxiety and the effective use of clickers in the classroom (Ashcraft, 2002; Bode et al., 2009; Bruff, 2009; Hoffman, 2010; Jain & Dowson, 2009; Kolikant et al., 2010; Lucas, 2009; Titman & Lancaster, 2011). In particular, the shift from passive to active learning that accompanies clicker use may help reduce students’ math anxiety (Clute, 1984; Titman & Lancaster, 2011). Several studies have suggested that the use of clickers may help make math courses more enjoyable for students and promote the development of positive attitudes toward mathematics (Bode et al., 2009; D’Inverno et al., 2003; Sharp, 2011). Positive attitudes about math have been correlated with lower levels of math anxiety (Adams & Holcomb, 1986; Bessant, 1995; Resnick et al., 1982).

The immediate feedback that clickers provide may help students develop confidence in their mathematical ability (Bode et al., 2009; Cline et al., 2008; Retkute, 2009; Woelk, 2008). Therefore, clicker use may contribute to increased mathematics self-efficacy due to the immediate feedback provided by the technology. Researchers have demonstrated a negative correlation between mathematics self-efficacy and math anxiety (Ashcraft, 2002; Clute, 1984; Pajares & Urdan, 1996). In other words, students with higher levels of math self-efficacy tend to have lower levels of mathematics anxiety. Since clicker use is hypothesized to contribute to higher levels of math self-efficacy, it seems plausible that clickers could contribute to decreased math anxiety.
Several researchers have found that students’ mathematics achievement increases when an instructor uses clickers in class (Gibson, 2011; Kolikant et al., 2010; Retkute, 2009; Strasser, 2010). In addition, previous studies have demonstrated a positive correlation between mathematics self-efficacy and achievement in mathematics (Bode et al., 2009; Kolikant et al., 2010). Unfortunately, not all potential connections between clicker use and math anxiety are desirable for educators or students. When an instructor counts clicker responses as part of students’ grades, some people may feel pressured to choose the correct answer quickly (Bruff, 2009; Caldwell, 2007). Thus, the stress of grading may increase students’ levels of test anxiety, which has a strong positive correlation with mathematics anxiety (Betz, 1978; Bruff, 2009; Cassady, 2010; Hembree, 1990; Wigfield & Meece, 1988).

**Significance of the Present Study**

The existing research literature in mathematics education contains a wealth of objective information relating clicker use, pedagogical choices, mathematics self-efficacy, math anxiety, and achievement in mathematics. However, a majority of the previous studies involved quantitative data that explain what interactions occur between variables. Usher’s (2009) qualitative study of mathematics self-efficacy among middle school students is a notable exception. A previous study provided quantitative data relating clicker use and math anxiety among students in an undergraduate calculus course (Batchelor, 2015). The present study sought to fill a gap in the literature and provide a deeper understanding of how and why the variables affect each other, with an emphasis on the subjective experiences of individual students. In addition, this dissertation study expanded on the previous study by including
math self-efficacy and achievement in mathematics as variables, and by incorporating qualitative data collection (student interviews) and analysis.

The conceptual framework was developed with the goal of producing a workable model that best fits the currently available data. As previously discussed, the framework implies possible mechanisms through which clicker use and the accompanying pedagogical changes may influence math self-efficacy, mathematics anxiety, and math achievement. More information is needed to explain how students perceive and experience the interactions among the variables in the model. I am not aware of any previous studies that have determined whether the negative correlation between mathematics anxiety and math self-efficacy holds in classes where clickers are used.

The research questions were developed with the objective of addressing gaps in the previous literature and testing the validity of the proposed mechanisms relating the variables. The present study sought to determine the effect of clicker use on the previously established correlations among mathematics anxiety, math self-efficacy, and achievement. Another goal for this study was to compare qualitative data from interview transcripts and observational fieldnotes with the quantitative data obtained from survey responses. The research questions were designed to represent a workable set of questions that effectively encompass the student experience and the most important connections among the variables in the conceptual framework.
CHAPTER 3. METHODOLOGY

The present study sought to provide a deep understanding of the relationships among clicker use, mathematics self-efficacy, math anxiety, and achievement in mathematics and to explore three proposed mechanisms that may underlie these relationships. With this purpose in mind, I developed four research questions to guide the study that pertain to quantitative data (correlations between variables such as mathematics anxiety, and math self-efficacy) and qualitative data (students’ perceptions and experiences related to clicker use, math anxiety, and other topics).

This chapter provides an overview of the quantitative and qualitative methodology I used when conducting this study. I first state the purpose of the study and the research questions and explain my rationale for choosing a mixed methods research design. Next, I describe the setting in which the study was conducted and the characteristics of the participants. I provide descriptions of the two survey instruments I have chosen to use and explain the process through which I conducted interviews with students and the course instructor. Finally, I summarize the process of collecting and analyzing the data, including quantitative analysis of survey responses and qualitative analysis of interview transcripts.

Research Questions

The present study explored four specific aspects of the conceptual framework using qualitative and quantitative data collection and analysis procedures. I developed the following list of research questions with the purpose of addressing the most important topics and connections represented in the conceptual framework.
1. What is the correlation between mathematics anxiety and math self-efficacy among students enrolled in an undergraduate calculus course involving the use of clickers? How is the correlation affected by the students’ demographic characteristics?

2. How does student achievement, as measured by students’ final course grades, correlate with math anxiety and mathematics self-efficacy in a calculus course involving the use of clickers? How are the correlations affected by the students’ demographic characteristics?

3. How do students perceive and experience the effect of clickers on their levels of mathematics anxiety and math self-efficacy and on their success in learning calculus? How do the students’ perceptions change over the course of the semester? How do the perceptions differ between students with low and high initial math anxiety levels?

4. How do students perceive and experience the relationships among mathematics self-efficacy, math anxiety, and achievement in a calculus class where clickers are used? How do the students’ perceptions change during the semester? How do the perceptions differ between students with high and low initial levels of mathematics anxiety?

**Research Design – Mixed Methods**

Based on the research questions, I determined a mixed methods study would be most effective in providing the desired answers. Teddlie and Tashakkori (2009) defined *mixed methods research* as “a type of research design in which qualitative and quantitative approaches are used in types of questions, research methods, data collection and analysis procedures, and/or inferences” (p. 7). Alternatively, Creswell (2015) defined *mixed methods* as “an approach to research in the social, behavioral, and health sciences in which the
investigator gathers both quantitative (closed-ended) and qualitative (open-ended) data, integrates the two, and then draws interpretations based on the combined strengths of both sets of data to understand research problems” (p. 2).

The first two research questions involve correlations between quantitative variables, while the last two questions pertain to the qualitative perceptions and experiences of students enrolled in an undergraduate calculus course as gathered through interviews. Thus, I perceived that a mixed methods study integrating quantitative and qualitative data within the conceptual framework I developed would be the most efficacious research design to provide meaningful answers to all of the research questions.

The present study was designed to extend previous research, which yielded quantitative data regarding the relationship between clicker use and math anxiety among calculus students (Batchelor, 2015). The previous study involved two large lecture calculus classes, one of which used clickers. The other class was taught in a traditional lecture format without clickers. The survey results indicated that the math anxiety levels were higher and increased at a faster rate in the non-clicker class than in the clicker class. However, no statistically significant difference in math anxiety was found between the classes at the beginning or end of the semester.

Among other factors, gender was found to be a significant predictor of math anxiety in the clicker class but not in the non-clicker class (Batchelor, 2015). Course enjoyment, test anxiety, and perceived math skill were determined to be significant predictors of math anxiety in both classes. Most of the students in the clicker class stated that the use of clickers helped them improve their understanding of calculus, and a strong majority reported that they participated more actively in class than they would have without clickers. This result
supported previous findings that clickers help promote student engagement and active learning (Bruff, 2009; Cline, 2006; Lock, 2011; Strasser, 2010; Woelk, 2008).

The present study sought to provide a deeper understanding of the mechanisms through which clicker use affects math anxiety and achievement, with an emphasis on mathematics self-efficacy and the subjective experiences of students who take a calculus course. The first two research questions pertain to the correlations between specific variables in the conceptual framework. In order to answer these questions, I conducted correlation analyses related to mathematics anxiety, math self-efficacy, and achievement in mathematics among students in an undergraduate calculus class where clickers were used regularly. Research Questions 3 and 4 relate to the qualitative perceptions and experiences of students in an undergraduate calculus course. I addressed these questions by interviewing students to explore how they perceived the relationships between clickers and the other components of the conceptual framework. In order to answer the research questions, I collected a substantial amount of qualitative and quantitative data and analyzed the data within the context of the conceptual framework. Therefore, the present study fits common definitions of mixed methods research (Creswell, 2015; Teddlie & Tashakkori, 2009).

Mixed methods research has several essential characteristics. In a mixed methods study, a researcher collects and analyzes quantitative and qualitative data using an organized set of research questions (Creswell & Plano Clark, 2011; Hesse-Biber, 2010). The research questions and procedures must be framed within a solid theoretical or conceptual framework (Creswell, 2015; Hesse-Biber, 2010). The researcher needs to connect the qualitative and quantitative data by merging the two forms of data, building one form upon the other, or embedding one form of data within the other (Creswell & Plano Clark, 2011; Creswell, 2015;
Teddie & Tashakkori, 2009). Mixed methods studies may prioritize one form of data over the other, or the researcher may give equal priority to both forms (Creswell, 2015; Hesse-Biber, 2010).

Based on the research questions, a mixed methods design seemed most appropriate for the present study. The first two research questions relate to the statistical correlations between variables including math anxiety, mathematics self-efficacy, and student achievement in mathematics. Thus, I perceived it was essential to obtain quantitative data regarding each variable using an appropriate measure. The remaining questions focus on the experiences and perceptions, related to the variables in the framework, of students who take an undergraduate calculus course.

In the present study, as the researcher, I sought to acquire a deep understanding of the mechanisms that relate clicker use, mathematics self-efficacy, math anxiety, and achievement in mathematics. In particular, clicker use and the accompanying pedagogical changes were hypothesized to facilitate positive classroom conditions leading to decreased math anxiety and higher levels of mathematics self-efficacy. On one hand, based on Bandura’s (1986) self-efficacy theory, an increase in the students’ math achievement is likely to follow. On the other hand, clickers may have little or no effect on the students’ achievement in mathematics or on their perceptions (based on interview data) of their levels of math anxiety or mathematics self-efficacy.

Site and participants

Research site. All data were collected at a large, public, Midwestern university during the Fall 2015 semester. The host university enrolls approximately 35,000 students.
Participants – full sample. The participants in the study were students in a large lecture section of an undergraduate calculus course at the host university during the Fall 2015 semester. The course (calculus) had an enrollment limit of approximately 192 students and reached capacity before the beginning of the semester. The instructor taught the course using clickers and also chose the format and frequency of the clicker activities. Prior to the course, the instructor agreed to cooperate in facilitating the study by allowing me to administer the surveys, interview students, and observe the class. The research plan was submitted and approved by the university’s Institutional Review Board prior to beginning the study (see Appendix A).

In order to determine the final sample for my dissertation study, I considered the number of students who took each of the two surveys, the number of matched pairs of pre and post surveys, and the completeness of data for each participating student. A total of 171 students took the first survey, while 128 students completed the second survey. In total, 176 students took at least one of the two surveys. Among the students who took the first survey, 48 students did not complete the second survey. Nine of these 48 students officially dropped the calculus course, and 14 received a grade of “F.” In addition, five students took the second survey but did not take the first survey.

The number of matched pairs of students who took both surveys was 123. Since a value of \( N \) greater than 100 is sufficient to facilitate inferential statistics and, considering the importance of matched pairs to the chosen statistical methods, I quickly made a decision to include only students who took both surveys (i.e., the matched pairs). Of the 123 students who took both surveys, all but one student received a standard grade ranging from “A” to “F.” The remaining student received a “P” (Pass) mark, which indicates that the student took
the course with a pass / no credit grading method and obtained a grade equivalent to “D–” or higher. Thus, the one student who received the “P” mark could have earned a grade anywhere from “A” to “D–” under the standard grading system. Given the importance of student achievement (as measured by the final course grades) as a variable in the statistical analysis, along with the fact that only one student received a “P” mark, I chose to omit this student from the sample. Therefore, the final sample \( (N) \) was comprised of 122 students who took both surveys and received a standard grade.

**Participants – interview subsample.** A subsample of four students was selected to participate in the interviews, and complete interim measures of math anxiety and mathematics self-efficacy. A survey was administered to the full sample at the beginning of the semester, and included a measure of the students’ math anxiety levels (see Appendix D). I computed the math anxiety scores for all students, including those who indicated an interest in participating in the interviews on the informed consent form. Among the male respondents, I selected students with both the highest and lowest math anxiety scores. Similarly, I selected female respondents with the highest and lowest math anxiety scores to participate in the interviews and complete the math anxiety and mathematics self-efficacy measures.

I assigned the following pseudonyms to each of the four students in the interview subsample: Larry (male, low math anxiety); Henry (male, high math anxiety); Linda (female, low math anxiety); and Hannah (female, high math anxiety). The four pseudonyms were deliberately chosen to reflect each student’s gender and initial level of math anxiety, based on the MAS results from the first survey. Specifically, the pseudonyms for the two students
identified as having low math anxiety begin with the letter “L,” while the pseudonyms for the participants with high math anxiety begin with the letter “H.”

Concurrent with the selection of the subsample participants, two alternate interviewees were selected for each participant in case an original interviewee dropped the course or chose not to continue participating in the study. The following process was employed to select the alternates for each interviewee. For the male, high anxiety interviewee, the two male students (among those who offered to participate in the interviews) with the next highest math anxiety scores were selected as the alternates and informed of their status as alternates in case the original participant left the study. A similar process was employed to select the alternates for the other three interviewees. Because all four of the students who participated in the first interview completed the course and participated in all of the remaining interviews, it was not necessary to use any of the alternate participants. Monetary compensation was offered as an incentive for the students to participate in the interviews.

In order to avoid biasing or influencing their responses during the interviews, the subsample participants were not told how they were selected. In particular, the interview participants were never told that they were identified as having high or low mathematics anxiety based on the first survey. This was a deliberate methodological decision to minimize the potential for the characterization as “low anxiety” or “high anxiety” to influence the participants’ responses. Of the four potential interview participants initially selected, three of the students accepted the invitation and participated in the four interviews. The student initially chosen to represent the female, high anxiety category declined the invitation to participate in the interviews, citing unanticipated time constraints. Thus, “Hannah” was the
female student with the second highest mathematics anxiety score, among the students who indicated an interest in participating in the interviews on the first survey. Table 3.1 provides a summary of the demographic characteristics of the students who participated in the study.

**Instructor.** The calculus instructor began teaching mathematics in 2008. Thus, he had seven years of teaching experience before the Fall 2015 semester, when data collection for the present study occurred. The instructor began teaching large lecture courses in 2011. His first experience teaching with clickers occurred during the Fall 2014 semester, one year before I collected the data for this study.

Table 3.1. Demographic data

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Categories</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>21</td>
</tr>
<tr>
<td>Age</td>
<td>18-20</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>21-24</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>25-30</td>
<td>1</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
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</tr>
<tr>
<td></td>
<td>African American</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Asian American</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Hispanic/Latino</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Native American</td>
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</tr>
<tr>
<td></td>
<td>Other</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Multiple</td>
<td>3</td>
</tr>
<tr>
<td>Completion of high school calculus</td>
<td>Yes, took calculus in HS</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>No, did not take HS calculus</td>
<td>31</td>
</tr>
<tr>
<td>Self-assessment of math skills at start of semester</td>
<td>Very weak</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Below average</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Above average</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Very strong</td>
<td>10</td>
</tr>
<tr>
<td>Grade in most recent math course (Self-Reported)</td>
<td>A</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>38</td>
</tr>
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<td></td>
<td>C</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>2</td>
</tr>
<tr>
<td>Self-assessment of test anxiety level at start of semester</td>
<td>No anxiety</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Mild anxiety</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>Moderate anxiety</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Serious anxiety</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Severe anxiety</td>
<td>1</td>
</tr>
</tbody>
</table>
Instruments

Surveys. The survey instruments used in the study included Betz’s (1978) Mathematics Anxiety Scale (MAS) as the measure of the participants’ math anxiety, and Betz and Hackett’s (1993) Mathematics Self-Efficacy Scale (MSES) as the measure of mathematics self-efficacy. The Mathematics Anxiety Scale was adapted from the anxiety subscale of Fennema and Sherman’s (1977) Mathematics Attitudes Scales. It is one of the two most frequently used instruments to measure mathematics anxiety (Hackett & Betz, 1989; Pajares & Urdan, 1996). The MAS is comprised of ten items scored on a five-point Likert scale. It has been independently verified to have strong reliability and validity. Betz, the author of the Mathematics Anxiety Scale, provided written permission to use the MAS in this study and reprint the survey questions (see Appendix B).

Betz (1978) revealed that the MAS has a split-half reliability coefficient of 0.92. Langenfeld and Pajares (1993) obtained a two-week test-retest reliability of 0.93 in a study involving 157 undergraduate students. In a study involving 769 undergraduates, Dew et al. (1983) reported a two-week test-retest reliability of 0.87 and a Cronbach’s alpha of 0.72. Pajares and Kranzler (1995) reported a Cronbach’s alpha of 0.90 in a study involving high school students, while Hackett and Betz (1989) obtained Cronbach’s alpha coefficients ranging from 0.86 to 0.90. Dew et al. (1983) determined that the MAS has a correlation of 0.67 with the 98-item Mathematics Anxiety Rating Scale (MARS), while Cooper and Robinson (1991) reported a correlation coefficient of 0.68. Pajares and Urdan (1996) conducted an exploratory factor analysis of the MAS and identified two factors, which they termed Worry and Negative Affective Reactions.
I chose to use Betz and Hackett’s (1993) Mathematics Self-Efficacy Scale (MSES) to measure math self-efficacy among the participants in my study. The MSES contains 34 items organized into two sections. All items are measured on a 10-point Likert scale ranging from (0) “No Confidence at All” to (9) “Complete Confidence” (Betz & Hackett, 1993). I purchased a license from the copyright holder, Mind Garden, Inc., permitting me to use the MSES in my research and include five sample items in this dissertation (see Appendix C).

The MSES has strong reliability and validity as verified by several researchers. Lent, Lopez, and Bieschke (1991) obtained a coefficient alpha (internal consistency reliability value) of 0.92 and a two-week test-retest reliability of 0.94 in their study of math self-efficacy and its relation to science-based career choices. Two years later, they reported a coefficient alpha of 0.94 in a study of math-related career choices (Lent, Lopez, & Bieschke, 1993). In their study of math self-efficacy and choices of science-based college majors, Betz and Hackett (1983) reported a coefficient alpha of 0.96 for the entire MSES instrument and alpha values of 0.92 for both subscales. Matsui, Matsui, and Ohnishi (1990) reported a coefficient alpha of 0.91 for the Japanese language version of the MSES in their study of mechanisms that underlie the development of self-efficacy beliefs.

The MSES has strong concurrent validity based on significant correlations with other measures of math attitudes. Betz and Hackett (1983) determined that the MSES total scores have correlations of –0.56, 0.66, 0.47, and 0.46, respectively, with other measures of math anxiety, math confidence, perceived usefulness of mathematics, and effectance motivation. The concept of *effectance motivation* refers to the extent to which a person is motivated by a desire to achieve a sense of competence or efficacy regarding a specific task, such as solving math problems (Pearlman, 1982; Pearlman, 1984; White, 1959). The established
relationships between MSES scores and math-based and science-based career choices provide additional evidence supporting the validity of the MSES (Betz & Hackett, 1983; Hackett, 1985; Hackett & Betz, 1989; Siegel et al., 1985). In a study involving 262 undergraduate students, Betz and Hackett (1983) used the MSES to measure math self-efficacy and found that students with higher levels of mathematics self-efficacy were significantly more likely to choose science-related college majors and career paths. Hackett (1985) used the MSES in her study of 117 undergraduates and determined that students with higher math self-efficacy were more likely to pursue math-related careers. These results provide evidence of the validity of MSES scores as a measure of students’ levels of mathematics self-efficacy.

Betz, author of the Mathematics Anxiety Scale and co-author of the Mathematics Self-Efficacy Scale, gave permission via email to use both instruments in the present study and to reprint the entire MAS instrument in my dissertation (see Appendix B). However, the copyright holder for the MSES (Mind Garden, Inc.) only permits authors to reprint five sample items from the MSES in a thesis or dissertation. The MAS items and five selected MSES items are included in Appendix C. I purchased a license from Mind Garden, Inc., which permitted me to print up to 500 copies of the MSES instrument.

The beginning-of-semester surveys contained a demographic questionnaire including the participants’ gender, age, race/ethnicity, high school math courses, perceived math self-efficacy, past math achievement, and test anxiety (see Appendix D). The questionnaire provided the demographic data necessary to answer Research Questions 1 and 2 (i.e., how the students’ demographic characteristics affect the correlations between variables in the conceptual framework). I included an informed consent document with the first survey. The
survey contained an item asking if the student was interested in participating in the interviews. The end-of-semester surveys included questions about topics such as the students’ enjoyment of the course, attendance, and expected grades (see Appendix D). The second survey also included some questions about the participants’ actual use of clickers and perceptions of the effects of using the technology. I asked the students to include their names on the surveys in order to match the two surveys for each participant.

**Interviews.** The four students in the subsample participated in interviews to discuss their perceptions of clicker use and the other elements of the conceptual framework. I offered monetary compensation of $24 per interview session for each interviewee as an incentive for students to participate, for a total of $96 for each participant who completed four interviews. Each interviewee received a single payment at the conclusion of his or her participation in the interviews.

I interviewed each student in the subsample four times during the semester (for a total of 16 interviews) and asked the students to complete the Mathematics Anxiety Scale and the Mathematics Self-Efficacy Scale during each interview session. Multiple interviews and administrations of the MAS and MSES were necessary to determine how the students’ perceptions, math anxiety levels, and mathematics self-efficacy levels changed during the semester in order to answer Research Questions 3 and 4. I conducted a single interview with the course instructor during the ninth week of the semester in order to obtain information related to his perspectives on clicker use, including many of the same topics discussed during the student interviews.

The purpose of the interviews was to collect qualitative data related to the students’ experiences and perceptions of the relationships among specific variables in the conceptual
framework, along with qualitative data related to the course instructor’s perspectives on teaching calculus with clickers. I developed the interview questions with this purpose in mind and with the goal of testing the validity of each of the three mechanisms proposed in the previous chapter. The four student interview protocols are included in Appendix E, along with the protocol for the instructor interview. The interview questions addressed both the cognitive and affective dimensions of mathematics anxiety.

In addition, I asked the students to reflect on their perceptions of their own math anxiety and mathematics self-efficacy. The interview questions addressed the students’ perceptions of their math self-efficacy and mathematics anxiety at different points in the course and helped determine how their perceptions changed during the semester. The students’ responses to these questions were analyzed in order to answer Research Questions 3 and 4. I compared the resulting qualitative data with the interviewees’ scores on the MSES and MAS measures. I believe the comparison of both forms of data provides evidence of the trustworthiness of the resulting data. For the student interviews, I compiled a matrix mapping the topics of the questions across the four rounds of interviews (see Appendix F). As shown in the matrix, I intentionally addressed several topics in all four rounds of student interviews in order to collect as much data as possible related to the changes in the students’ perspectives during the semester.

**Data collection**

The data collection process began during the second week of the Fall 2015 semester. Because students were free to drop and add courses and switch sections during the first week of the semester, I chose to wait until the second week so the class roster was firmly established before I began collecting data. On Monday of the second week, I administered
the first survey during class time, at the beginning of the class period. All students in the class, with the exception of those younger than 18 years of age, were invited to take the survey. I made a brief verbal announcement to the class and then distributed the survey materials, which comprised two copies of an informed consent document, the Mathematics Anxiety Scale and Mathematics Self-Efficacy Scale instruments, and a demographic questionnaire. Participating students were asked to detach and save the first copy of the informed consent document and to sign and return the second copy along with the surveys.

After administering the first survey, I identified the interview subsample participants in accordance with the process described previously. Once the interviewees were identified, I contacted each subsample participant to schedule the first interview session. The four interview sessions for each subsample participant occurred at intervals of approximately three weeks between interviews, with the first interviews conducted during the fourth week of the semester and the final interviews completed during the thirteenth week. At the beginning of the first interview session for each subsample participant, I asked the interviewee to read and sign an informed consent document specific to the interview portion of the study.

Next, I asked the student to take the Mathematics Anxiety Scale and the Mathematics Self-Efficacy Scale. I administered the MAS and MSES before each interview in order to prevent the content of the interview from influencing the student’s responses on the scales. Finally, I began the audio-recorded interview. The interviews had a semi-structured format. I prepared a list of questions for each interview but allowed the interviews to include discussion of topics external to the prepared questions. Each recorded interview lasted
approximately 25 to 30 minutes, and I completed the entire data collection session within an hour for all instances.

The second and third interview sessions for each subsample participant had the same format as the first session, with the exception of the informed consent process (which was only completed once for each interviewee). I administered the MAS and MSES measures and then conducted the recorded interviews. The fourth interview session followed the same format but concluded with the payment process. Each of the four subsample participants completed all four interviews and received full compensation at the time of the final interview.

I interviewed the course instructor during the ninth week of the semester in order to collect data related to his perspectives on teaching calculus using clickers. The interview protocol for the instructor interview covered many of the same topics addressed during the student interviews. For these topics, the phrasing of the questions was edited to reflect the instructor’s perspectives related to the topics. In addition, I asked the instructor general questions pertaining to his teaching experience and pedagogical philosophy. The instructor interview lasted approximately 40 minutes.

The final point of data collection occurred during class time on Wednesday of the week after the Thanksgiving holiday. The procedure for administering the end of semester survey was very similar to the procedure for the first survey, with the exception of the informed consent process, which was only completed with the initial survey. I invited all students in the class, including the four interviewees, who were at least 18 years of age to take the survey. I made a verbal announcement to the class and then distributed the survey materials, which comprised the MAS and MSES measures, a series of questions about the
students’ perceptions and experiences with clicker use, and a few questions about the students’ general perspectives on the course. Table 3.2 provides a summary of the data collection process utilized in the study.

I passively observed the class four times (50-minute class periods) during the semester. The classroom observations occurred at intervals of approximately three weeks. I prepared a class observation protocol, which I used to systematize the observations (see Appendix E). I took fieldnotes during the observations but did not use any audio or video recording equipment. The purpose of the class observations was to gain a sense of the ways in which the instructor interacted with the students and structured the clicker activities. However, the classroom observations were not a substantive source of data comparable to the surveys and student interviews.

The instructor began each lecture by writing a brief summary of the topics he planned to cover on the chalkboard, along with announcements related to upcoming homework due

<table>
<thead>
<tr>
<th>Table 3.2. Six points of data collection</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time 1</strong></td>
</tr>
<tr>
<td>1st survey</td>
</tr>
<tr>
<td>Announcement</td>
</tr>
<tr>
<td>Full Sample</td>
</tr>
<tr>
<td>Interview Subsample</td>
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<tr>
<td></td>
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</tr>
</tbody>
</table>
dates or examinations. Next, he spent approximately two or three minutes verbally summarizing the lecture agenda and announcements. He then provided a brief review of the material from the previous lecture and began presenting new content. The instructor generally presented new material using the chalkboard but occasionally displayed graphs or other content using the classroom projector. He appeared to have a good rapport with the students, who laughed at his occasional jokes and generally seemed attentive throughout the lectures. The instructor always worked through at least one example problem pertaining to a given topic before presenting a related clicker question.

Each of the observed lectures included one clicker question, although the interview participants indicated that the instructor occasionally presented two clicker problems during the same lecture. When he introduced the clicker problem, he sometimes stated, “I’ve had too much fun. Now it’s time for you to have fun,” or something similar. The timing of the clicker questions varied; the questions were presented between twenty and 40 minutes into a class period (50 minutes in length) during the observed lectures. The instructor presented all of the observed clicker problems in multiple-choice format. The questions typically had four response choices. However, one of the observed questions (pertaining to whether a given series converges) had only three choices, which corresponded to the three possible outcomes of absolute convergence, conditional convergence, and divergence.

The format of the clicker questions was consistent across all of the observed lectures. The instructor displayed the problem on the projector screen, which was connected to his laptop computer. The students worked on the problem individually for 4-6 minutes and then voted for one of the response choices. Next, the instructor asked the students to discuss the problem in pairs or small groups and vote a second time. The students took approximately 2-
3 minutes to discuss the problem before the second poll. The number of students who responded to each clicker problem gradually decreased from 163 to 138 over the course of the observed lectures, most likely due to students withdrawing from the course as the semester progressed. After the students completed the second poll, the instructor displayed histograms showing the percentage of students who voted for each response choice during the first and second poll.

During all of the observed lectures, the number of students who voted for the correct response increased from the first poll to the second. The magnitude of the increase varied from 3% (from 47% to 50% correct) to 36 percent (from 32% to 68% correct). The correct response was the most popular choice during the second poll in all of the observed lectures. However, one of the interview participants referenced a lecture during which the most popular choice was incorrect. The instructor generally explained the complete solution to each clicker problem using the chalkboard after displaying the histograms, with the exception of one observed lecture during which he only provided a brief verbal explanation due to time constraints. Depending on the amount of time available, he then continued presenting new material or concluded the lecture. The instructor provided a brief preview of the next topic at the end of one observed class period. At the conclusion of a lecture, he sometimes reminded students of upcoming examinations or homework due dates.

I obtained the final grades in the calculus course for all participants in the study as a measure of mathematics achievement by following the host university’s established procedure for obtaining de-identified student records from the Office of the Registrar. The final grades served as the measure of mathematics achievement for all participants in the study and were an essential component of the quantitative analysis.
Data analysis

Students responded to each Mathematics Anxiety Scale item on a five-point Likert scale according to the instructions that Betz (1978) provided when she published the MAS instrument. This process yielded a total MAS score between 10 and 50 for each student, with higher scores indicating higher levels of math anxiety. On the MSES measure, students responded to each item on Likert scale from 0 through 9 according to the instructions Betz and Hackett (1993) provide on the first page of the instrument. The MSES responses were scored by following the instructions provided in the scoring guide that accompanies the measure. Possible MSES scores range from 0 to 9, corresponding to the ten-point Likert scale for individual questions. The Likert scale scores for the questions were averaged to determine the total MSES score. Statistical software (IBM® SPSS® Statistics) was used to conduct the quantitative analysis.

Correlation analyses were conducted to determine the correlations between math self-efficacy and math anxiety, between math anxiety and math achievement, and between math self-efficacy and math achievement. Paired samples t-tests were used to analyze the change in all participants’ levels of math anxiety and mathematics self-efficacy during the semester. The MSES scores were also compared to normative data that Betz and Hackett (1993) provided in the training manual for the instrument. I used the factorial analysis of variance (ANOVA) technique to determine the effect of demographic variables on the participants’ levels of math anxiety, mathematics self-efficacy, and student achievement. The factorial ANOVA technique was also used to determine the effect of the students’ self-reported course enjoyment, attendance, and expected course grade on the variation in the end of semester MAS and MSES scores.
I conducted independent samples $t$-tests to compare the initial levels of math anxiety and math self-efficacy between students who took both surveys and students who only completed the first survey and were thus omitted from the sample. Regarding the six MAS and MSES scores for each interview participant, it was not be possible to conduct inferential statistical analysis due to the small size of the subsample ($N = 4$). Thus, I represented the scores visually by including graphs showing the six MAS and MSES scores for each interviewee.

I transcribed all of the recorded interviews and used a systematic coding process to identify emergent themes from the data. In his qualitative coding manual, Saldaña (2009) described first cycle and second cycle coding methods. First cycle coding methods are relatively simple and involve assigning codes to specific statements or excerpts from a document such as an interview transcript. Second cycle methods are more complex and involve classifying and synthesizing the codes to identify emergent themes.

I prepared a preliminary list of codes representing anticipated themes based on a comprehensive review of the relevant literature (see Appendix F). However, I was open to adding codes to the list during the coding process. I began by assigning codes to the interviewees’ statements on each of the individual transcripts, a process consistent with first cycle coding as described by Saldaña (2009). After completing the first cycle coding for all 17 transcripts (16 student interviews and the instructor interview), I prepared a matrix to organize the students’ responses by question topic (see Appendix F). The matrix consists of three columns: sociological codes (identified via the literature review), “En Vivo” codes (brief excerpts in the participants’ own words), and sample quotations from the interview questions relevant to each topic. Within each general topic, I organized the “En Vivo” codes
and sample quotations into subtopics, which I subsequently used to generate themes based on the totality of the interview responses. This process is consistent with Saldaña’s (2009) conceptualization of second cycle coding.

Ongoing member checks were conducted during the second, third, and fourth interviews with each participating student to ensure that my interpretations of the interviewees’ statements were reasonably consistent with the perspectives the participants intended to express. Upon completion of each of the first three interviews with a specific student, I promptly transcribed the interview. I subsequently annotated the next interview protocol for the same student with a brief summary of the student’s responses to questions on similar topics from all previous interviews. During the second, third, and fourth interviews with each student, I conducted the member checks by asking the participants to verify the consistency of my interpretations of their responses from preceding interviews with the perspectives they wanted to convey. I was especially attentive to the member checks in cases where a student’s response appeared to differ from his or her responses to similar questions from previous interviews. I carefully compared the quantitative and qualitative data to gain a deeper understanding of the relationships among mathematics self-efficacy, math anxiety, and achievement in mathematics. This comparison involved examining whether the themes identified from the interview transcripts were consistent with the statistical data obtained from the survey questions and the MAS and MSES instruments.
CHAPTER 4. RESULTS

Chapter 3 provided the research methodology for this dissertation study, including my rationale for selecting a mixed methods research design, along with the specific quantitative and qualitative methods used to collect and analyze the data. The present chapter provides a summary of the results obtained from the data analysis. The organization of this chapter is based on the four research questions. The first two questions are addressed primarily by the statistical analysis of quantitative survey responses. Qualitative analysis of interview transcripts was employed to answer Research Questions 3 and 4.

Table 4.1 provides a summary of the descriptive statistics for the variables included in the statistical analysis. The numerical values in the table require some explanation since the values correspond to the process used to code the participating students’ survey responses.

The instructor began each lecture by writing a brief summary of the topics he planned to cover on the chalkboard, along with announcements related to upcoming homework due. Higher values for the pre and post MSES total scores correspond to higher levels of math self-efficacy (i.e., greater confidence in the students’ mathematical ability). The possible scores on the MSES range from 0 (least confident) to 9 (most confident).

The final course grades obtained from the Office of the Registrar were coded based on the standard grade point average (GPA) scale, where A = 4.00, A– = 3.67, B+ = 3.33, B = 3.00, …, D = 1.00, D– = 0.67, and F = 0.00. The self-reported expected course grades (from the end of semester survey) and the self-reported grade in last math course (from the first survey) were also coded using the standard GPA scale, although the only answer choices were A, B, C, D, and F (coded as 4, 3, 2, 1, and 0, respectively). Data for the perceived math
Table 4.1. Descriptive statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Min</th>
<th>Max</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre MAS Total Score</td>
<td>25.80</td>
<td>7.01</td>
<td>13.00</td>
<td>46.00</td>
<td>0.42</td>
<td>–0.33</td>
</tr>
<tr>
<td>Post MAS Total Score</td>
<td>25.00</td>
<td>7.53</td>
<td>11.00</td>
<td>42.00</td>
<td>0.16</td>
<td>–0.60</td>
</tr>
<tr>
<td>Pre MSES Total Score</td>
<td>7.01</td>
<td>1.08</td>
<td>1.50</td>
<td>8.60</td>
<td>–1.88</td>
<td>5.93</td>
</tr>
<tr>
<td>Post MSES Total Score</td>
<td>7.23</td>
<td>0.90</td>
<td>3.00</td>
<td>8.80</td>
<td>–1.46</td>
<td>4.09</td>
</tr>
<tr>
<td>Final Course Grade</td>
<td>2.72</td>
<td>0.97</td>
<td>0.00</td>
<td>4.00</td>
<td>–0.44</td>
<td>–0.17</td>
</tr>
<tr>
<td>Expected Grade</td>
<td>2.93</td>
<td>0.83</td>
<td>0.00</td>
<td>4.00</td>
<td>–0.58</td>
<td>0.42</td>
</tr>
<tr>
<td>Last Math Grade</td>
<td>3.03</td>
<td>1.02</td>
<td>0.00</td>
<td>4.00</td>
<td>–0.99</td>
<td>0.31</td>
</tr>
<tr>
<td>Perceived Math Skill</td>
<td>3.73</td>
<td>0.69</td>
<td>2.00</td>
<td>5.00</td>
<td>–0.34</td>
<td>0.18</td>
</tr>
<tr>
<td>Perceived Test Anxiety</td>
<td>2.34</td>
<td>0.73</td>
<td>1.00</td>
<td>5.00</td>
<td>0.43</td>
<td>0.84</td>
</tr>
<tr>
<td>Course Enjoyment</td>
<td>3.38</td>
<td>1.01</td>
<td>1.00</td>
<td>5.00</td>
<td>–0.52</td>
<td>0.04</td>
</tr>
<tr>
<td>Attendance</td>
<td>4.56</td>
<td>0.74</td>
<td>1.00</td>
<td>5.00</td>
<td>–2.07</td>
<td>5.28</td>
</tr>
<tr>
<td>Clicker Usefulness</td>
<td>26.55</td>
<td>4.76</td>
<td>13.00</td>
<td>39.00</td>
<td>–0.17</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Skill and perceived test anxiety variables were collected during the first survey. For perceived math skill, the responses were coded on a five-point Likert scale, where higher scores correspond to higher levels of self-reported math skill level. The mean value of 3.73 falls between (3) “Average” and (4) “Above Average” math ability. The responses for perceived test anxiety were coded on a five-point Likert scale, with higher scores reflecting higher levels of self-reported test anxiety. The mean value of 2.34 is between (2) “Mild Anxiety” and (3) “Moderate Anxiety.”

The data for the self-reported variables of course enjoyment and attendance were collected during the second survey near the end of the semester. For course enjoyment, the responses were coded on a five-point Likert scale, where higher scores correspond to higher levels of enjoyment. The mean value of 3.38 falls between (3) “Somewhat Enjoyable” and (4) “Very Enjoyable.” The responses for attendance were coded on a five-point Likert scale, with higher scores reflecting better attendance (i.e., fewer absences during the semester).
The mean value of 4.56 is between (4) “3-5 Days Absent” and (5) “0-2 Days Absent.”

Finally, the scores for the variable termed “Perception of Clicker Usefulness” were based on a set of eight questions on the end of semester survey. The responses to each question were coded on a five-point Likert scale, with higher scores corresponding to more favorable perceptions of the clicker activities. The values for “Perception of Clicker Usefulness” were obtained by adding the scores for the eight questions. Thus, the range of possible values is from 8 (least positive perception of clickers) to 40 (most positive perception of clicker use).

**Research Question 1: Correlation between Math Anxiety and Math Self-efficacy, Relationship to Demographic Characteristics**

The first research question pertained to the correlation between mathematics anxiety and math self-efficacy, along with the extent to which the students’ demographic characteristics predicted the variation in their math self-efficacy and math anxiety. This section begins with a summary of data related to the participating students’ levels of mathematics self-efficacy and math anxiety obtained from the two surveys and also includes an analysis of the change in mathematics anxiety and math self-efficacy over the course of the semester. Factorial ANOVA results are interpreted to address the effects of the students’ demographic characteristics on their levels of math self-efficacy and mathematics anxiety.

**Math anxiety and self-efficacy levels at beginning and end of semester**

The means (with standard deviations in parentheses) for the MAS total scores were 25.80 (7.01) at the beginning of the semester and 25.00 (7.53) near the end of the semester. The values for the MSES were 7.01 (1.08) for the first survey and 7.23 (0.90) for the second survey. In the MSES training manual, Betz and Hackett (1993) provided normative data to assist researchers with interpreting MSES results when the instrument is administered to a
sample of undergraduate students. Based on the normative data, the mean values for the pre and post MSES total scores correspond approximately to the 70th and 75th percentiles, respectively.

At the beginning of the semester, the correlation between MAS and MSES scores was \( r = -0.37 \), with a corresponding significance value of \( p < 0.01 \). The correlation for the second survey was \( r = -0.43 \), with significance value \( p < 0.01 \). Thus, a significant negative correlation between math anxiety and mathematics self-efficacy was present during both surveys. This result is consistent with previous findings that students with higher levels of math anxiety tend to be less confident in their math ability (Akin & Kurbanoglu, 2011; Bandalos et al., 1995; Clute, 1984; Cooper & Robinson, 1991; Hackett, 1985; Hoffman, 2010; Jameson, 2010; Lyons & Beilock, 2012; Matsui et al., 1990; May, 2009; Park et al., 2014; Usher, 2009). The magnitude of the correlation increased somewhat from the first survey \( (r = -0.37) \) to the second survey \( (r = -0.43) \).

**Change in math anxiety and math self-efficacy during the semester**

Paired samples \( t \)-tests were conducted to analyze the changes in the MAS total scores and the MSES total scores during the semester. For the MAS scores, the means (and standard deviations) were 25.80 (7.01) at the beginning of the semester and 25.00 (7.53) near the end of the course. The mean difference score (pre – post) was 0.80, with a standard deviation of 4.99. The paired samples \( t \)-test yield a value of \( t = 1.78 \), with a two-tailed significance value of 0.08, indicating that the change in mathematics anxiety during the semester did not meet conventional standards for statistical significance. Although the mean
MAS total score decreased slightly from the first survey to the second survey, the decrease was not statistically significant.

A similar analysis was conducted to determine whether a significant change in mathematics self-efficacy, as measured by the MSES scores, occurred during the semester. For the MSES scores, the means (and standard deviations) were 7.01 (1.08) for the first survey and 7.23 (0.90) for the second survey. The mean difference score (pre – post) was –0.22, with a standard deviation of 0.71. The paired samples $t$-test yielded a value of $t = –3.46$, with a two-tailed significance value of $p < 0.01$, indicating that a significant increase in the MSES total scores occurred during the semester. On the surface, this result suggests that students’ confidence in their math ability increased significantly from the first survey to the second survey. However, since the sample does not include the students who dropped the course before the second survey was administered, it is possible that the apparent increase in mathematics self-efficacy could be attributed to a “survivor effect.”

**Effect of demographic characteristics**

A factorial ANOVA was conducted to determine the effect of gender, age, and race/ethnicity on the participants’ math anxiety and mathematics self-efficacy levels. The first analysis was conducted using the end of semester MAS scores as the dependent variable. Levene’s test yielded a value of $F = 0.83$, with a corresponding significance value of 0.62. Thus, it is reasonable to assume equal error variances across groups. For gender, a value of $F = 0.03$ was obtained, with a corresponding significance value of 0.87. The values obtained for age were $F = 1.63$, with significance value 0.20. For race/ethnicity, a value of $F = 1.26$ was obtained, with significance value 0.29. Therefore, none of the demographic variables
tested (gender, age, and race/ethnicity) had a significant effect on mathematics anxiety, as measured by the MAS scores.

The second factorial ANOVA was conducted using the end of semester MSES scores as the dependent variable. Levene’s test yielded a value of $F = 2.92$, with a corresponding significance value of $p < 0.01$. This result suggests the presence of significant group differences, so I could not assume equal error variances across groups. For gender, a value of $F = 0.02$ was obtained, with a corresponding significance value of 0.88. The values obtained for age were $F = 2.40$, with significance value 0.10. For race/ethnicity, a value of $F = 2.48$ was obtained, with significance value 0.04. Therefore, race/ethnicity was found to have a significant effect on the variation in MSES scores, while the other demographic variables tested (gender and age) did not have a significant effect on mathematics self-efficacy, as measured by the MSES scores.

The response choices for race/ethnicity in the demographic questionnaire were African American, Asian American, Hispanic/Latino, Native American, White (Caucasian), and Other (see Appendix D). Participants who identified as Hispanic/Latino had significantly higher levels of math self-efficacy than the students who identified as Asian American or chose the “Other” category. Students who identified as White (Caucasian) had significantly higher levels of mathematics self-efficacy in comparison to students who identified as Asian American or selected “Other.” Table 4.2 displays the mean MAS score, mean MSES score, mean final course grade, and percentage of students in each race/ethnicity category. Although no participants identified as Native American, this category is included to clarify the meaning of the “Other” category.
Table 4.2. Dependent variables by race/ethnicity

<table>
<thead>
<tr>
<th>Race/Ethnicity</th>
<th>Percentage of Students</th>
<th>Mean MAS Score</th>
<th>Mean MSES Score</th>
<th>Mean Final Course Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>White (Caucasian)</td>
<td>75</td>
<td>25.00</td>
<td>7.30</td>
<td>2.73</td>
</tr>
<tr>
<td>African American</td>
<td>3</td>
<td>25.33</td>
<td>7.57</td>
<td>2.45</td>
</tr>
<tr>
<td>Asian American</td>
<td>8</td>
<td>28.80</td>
<td>6.42</td>
<td>2.63</td>
</tr>
<tr>
<td>Hispanic/Latino</td>
<td>4</td>
<td>16.60</td>
<td>7.84</td>
<td>3.13</td>
</tr>
<tr>
<td>Native American</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
<td>24.22</td>
<td>6.89</td>
<td>3.11</td>
</tr>
<tr>
<td>Multiple</td>
<td>3</td>
<td>28.33</td>
<td>7.60</td>
<td>1.33</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
<td><strong>25.00</strong></td>
<td><strong>7.23</strong></td>
<td><strong>2.72</strong></td>
</tr>
</tbody>
</table>

When interpreting the statistical significance of the effect of race/ethnicity on the MSES scores, it is important to consider the practical significance of the results. Participants who identified as Hispanic/Latino had significantly higher levels of math self-efficacy than the students who identified as Asian American or chose the “Other” category, in the context of statistical significance. However, the percentages of students in the categories differed, with only 4 percent of students identifying as Hispanic/Latino, compared with 8 percent for Asian American and 7 percent for “Other.” In addition, the “Other” category is ambiguous because it may include students who identify as members of different racial/ethnic groups. From a statistical standpoint, students who identified as White (Caucasian) had significantly higher levels of mathematics self-efficacy in comparison to students who identified as Asian American or selected “Other.” Since 75 percent of the participants identified as White (Caucasian), compared to 8 percent for Asian American and 7 percent for “Other,” one must be especially careful when interpreting the practical significance of these group differences.
**Research Question 2: Correlations between Student Achievement (Grades) and Math Anxiety (MAS Scores), Student Achievement (Grades) and Math Self-efficacy (MSES Scores), Effect of Demographic Characteristics**

The final course grades obtained from the registrar were coded based on the standard GPA scale, where A = 4.00, A− = 3.67, B+ = 3.33, B = 3.00, … , D = 1.00, D− = 0.67, and F = 0.00. The mean for the final course grade was 2.72, with a corresponding standard deviation of 0.97. The correlation between the MAS total scores at the beginning of the semester and the final course grades was −0.54, with a corresponding significance value of $p < 0.01$. The correlation between the end of semester MAS total scores and the final course grades was −0.53, with significance value $p < 0.01$. Thus, a significant negative correlation was present between mathematics anxiety (as measured by the MAS total scores) and student achievement (measured by final course grades) for both surveys\(^1\). This result is consistent with previous findings that students with higher levels of math anxiety tend to demonstrate decreased achievement in mathematics (Dew et al., 1984; Hembree, 1990).

The correlation between the MSES total scores at the beginning of the semester and the final course grades was 0.24, with a corresponding significance value of 0.01. The correlation between the end of semester MSES total scores and the final course grades was 0.18, with significance value 0.04. Therefore, there was a significant positive correlation between mathematics self-efficacy and student achievement both at the beginning of the course and near the end of the semester. This finding is consistent with previous studies showing that students who are more confident in their mathematical ability typically perform better in mathematics (Hackett & Betz, 1989; Pajares & Kranzler, 1995).

\(^1\) In addition, this result appears to support Bandura’s (1986) theory of self-efficacy.
Effect of demographic characteristics

A factorial ANOVA was conducted to determine the effect of gender, age, and race/ethnicity on student achievement, as measured by the final course grades. Levene’s test yielded a value of $F = 1.37$, with a corresponding significance value of 0.18. Thus, it is reasonable to assume equal variances across groups. For gender, a value of $F = 0.32$ was obtained, with a corresponding significance value of 0.57. The values obtained for age were $F = 1.08$, with significance value 0.34. For race/ethnicity, a value of $F = 1.86$ was obtained, with a significance value of 0.11. Therefore, none of the demographic variables tested had a significant effect on the students’ final course grades.

Math anxiety, math self-efficacy, and student perceptions of calculus course

A factorial ANOVA was conducted to determine the effect of self-reported variables (course enjoyment, attendance, and expected grade) on the variation in the end of semester MAS and MSES total scores. The first analysis was conducted using the end of semester MAS total scores as the dependent variable. Levene’s test yielded a value of $F = 1.35$, with a significance value of 0.14. Thus, one can reasonably assume equal variances across groups. For course enjoyment, a value of $F = 3.45$ was obtained, with significance value 0.01. The values obtained for attendance were $F = 3.41$, with a corresponding significance value of 0.01. For expected grade, we obtain a value of $F = 3.59$, with significance value 0.01. Therefore, all of the self-reported variables tested (course enjoyment, attendance, and expected grade) were found to have a significant effect on mathematics anxiety, as measured by the MAS total scores.
While the significant effect of course enjoyment, attendance, and expected grade on the students’ math anxiety is notable, the positive direction of the relationships is surprising. The responses to the survey questions were coded such that higher values correspond to greater enjoyment of the course, better attendance (fewer days absent), and higher expected grades, respectively. Higher scores on the MAS instrument correspond to higher levels of math anxiety. Thus, the positive direction of the relationships indicates that students with higher levels of math anxiety enjoyed the course more, had better attendance, and expected higher grades, in comparison to students with lower math anxiety levels. This result was unexpected, and there appears to have no clear explanation for the surprising result.

The second factorial ANOVA was conducted using the end of semester MSES scores as the dependent variable. Levene’s test yielded a value of $F = 1.43$, with significance value 0.10. Therefore, it is reasonable to assume equal variances across groups. For course enjoyment, a value of $F = 1.50$ was obtained, with a corresponding significance value of 0.21. The values obtained for attendance were $F = 1.30$, with significance value 0.28. For expected grade, a value of $F = 1.47$ was obtained, with a corresponding significance value of 0.22. One may conclude that none of the self-reported variables tested (course enjoyment, attendance, and expected grade) had a significant effect on the participating students’ mathematics self-efficacy. Table 4.3 provides a summary of the students’ responses to the three questions applicable to the previously referenced factorial ANOVA analyses.

**Comparison of initial MAS and MSES scores between students who completed both surveys versus students who only completed first survey**

Independent samples $t$-tests were conducted to determine whether the initial MAS total scores and MSES total scores differed significantly between students included in the
Table 4.3. Student responses to end-of-semester questions

<table>
<thead>
<tr>
<th>Question</th>
<th>Categories</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>To what extent have you found this course enjoyable?</td>
<td>Extremely Enjoyable</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Very Enjoyable</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Somewhat Enjoyable</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Slightly Enjoyable</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Not Enjoyable at All</td>
<td>6</td>
</tr>
<tr>
<td>Approximately how many times have you been absent from this course?</td>
<td>0-2 Days Absent</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>3-5 Days Absent</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>6-9 Days Absent</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>10-15 Days Absent</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>16 or More Days Absent</td>
<td>1</td>
</tr>
<tr>
<td>What grade do you expect to receive in this course?</td>
<td>A</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>1</td>
</tr>
</tbody>
</table>

Note. Percentages for some categories do not add to 100% due to rounding.

The mean scores (with standard deviations in parentheses) for the MAS total scores at the beginning of the semester were 25.67 (7.12) for the students who took both surveys and 29.19 (7.11) for the students who only completed the first survey. The independent samples $t$-test yielded a value of $t = -2.90$, with a corresponding two-tailed significance value of $p < 0.01$, where equal variances are assumed. If one does not assume equal variances, the resulting values are $t = -2.90$, with significance value 0.01. Thus, a significant difference was found to be present in the beginning of semester MAS total scores between students who took both surveys and students who only took the first survey.
For the beginning of semester MSES total scores, the mean scores (with standard deviations in parentheses) were 7.02 (1.09) for the students who took both surveys and 6.98 (1.11) for the students who only completed the first survey. An independent samples t-test yielded a value of \( t = 0.21 \), with a corresponding two-tailed significance value of 0.84, where equal variances are assumed. If we do not assume equal variances, the resulting values are \( t = 0.20 \), with significance value 0.84. We conclude that there is no significant difference between the beginning of semester MSES total scores between students who took both surveys and students who only completed the first survey, regardless of whether equal variances are assumed.

**Student perceptions of clicker use**

The second survey, which was administered during the fourteenth week of the semester, included a series of eight questions pertaining to the students’ opinions and perspectives on using clickers in the calculus course. Figure 4.1 includes bar charts summarizing the students’ responses to each of the eight questions about clicker use.

**Interview participants’ math anxiety and self-efficacy**

In addition to taking the MAS and MSES instruments as part of the two surveys administered during class time, the four interview participants also took the MAS and MSES instruments during each of the four interview sessions. Thus, each interview participant completed the MAS and MSES a total of six times (two surveys and four interviews). Since inferential statistics were not feasible with a subsample size of \( N = 4 \), I chose to represent the interviewees’ MAS and MSES responses visually. Figures 4.2 and 4.3 illustrate the six scores for each interview participant on the MAS and MSES, respectively.
Q1. I have attended class more frequently than I would have if the instructor did not use clickers.

Q2. I expect to earn a higher grade than I would have without using clickers.

Q3. I have enjoyed the course more because of the clickers.

Q4. The use of clickers has helped me improve my understanding of calculus concepts.

Q5. I participated in class more actively than I would have without clickers.

Q6. The clickers have helped me become more confident in my math ability.

Q7. The use of clickers has helped to decrease my level of math anxiety.

Q8. I would encourage other math instructors to use clickers in their classes.

KEY: SD = Strongly Disagree, D = Disagree, U = Undecided, A = Agree, SA = Strongly Agree

Figure 4.1. Student responses to questions about clicker use
Figure 4.2. Mathematics anxiety scale scores for interview participants

Figure 4.3. Mathematics self-efficacy scale scores for interview participants
Research Question 3: Student Perceptions of Effect of Clickers on Math Anxiety, Math Self-efficacy, and Achievement; Change in Perceptions during Semester; Differences between Students with Low and High Initial Math Anxiety Levels

The third research question addressed the students’ perspectives on the effect of clicker use on the students’ math anxiety, mathematics self-efficacy, and achievement in mathematics. I was particularly interested in identifying changes in the students’ responses during the semester, as well as differences between the responses provided by students initially identified as having low and high levels of mathematics anxiety. The student interviews were the primary mode of data collection used to answer Research Questions 3 and 4. As stated in Chapter 3, I chose the four pseudonyms to be suggestive of gender and initial math anxiety level (low or high, indicated by the first letter of each pseudonym), as measured by the first survey. Specifically, I assigned the following pseudonyms to each of the four students in the interview subsample:

- Larry (male, low math anxiety)
- Henry (male, high math anxiety)
- Linda (female, low math anxiety)
- Hannah (female, high math anxiety)

Effect of clickers on mathematics anxiety

Each of the four interviews included a question about the effect of using clickers on the participants’ mathematics anxiety. Some of the responses indicated a direct or immediate effect on math anxiety during the clicker activities. Hannah (Interview 1) stated, “It helps me to encounter my math anxiety. It helps me to think that a math question is something I can do.” Linda (Interview 1) remarked, “It’s like a comfort if you got it wrong and then other people got it wrong.” During the final interview, Linda stated, “I think the clickers have
decreased it [anxiety]. It’s just like practice problems that are mandatory, so not much stress at all.” Larry (Interview 1) spoke of increased anxiety while working on the clicker problems: “The time limit does kind of stress me out, but otherwise, it doesn’t really stress me out overall.” Henry (Interview 2) stated, “The clickers do make me less comfortable than I would be if there were no clickers. It makes me pay attention and stay engaged.” During the second interview, Linda remarked, “During the problems leading up to it, you’re kind of, like, very attentive because you know you’re going to be immediately quizzed on it.” Larry (Interview 2) added, “I can see how it could make you more anxious, as they do seem more difficult than the example problems.”

Some responses were indicative of an indirect effect of clickers on math anxiety via identification of errors and improved study habits. Hannah (Interview 2) remarked, “It makes be a bit nervous if a question is presented and I need to answer it, but the nervousness actually helps me to feel comfortable during the exam because I have the experience of having a sudden question.” According to Linda (Interview 3), “In the moment, I guess it raises my anxiety a little bit, but then he goes through it and it’s not really stressful. Long-term, I think it’s good because you’re getting, like, practice quizzes every day.” During the fourth interview, Henry stated, “I would say the clickers have helped deal with my anxiety because at least I know where I’m strong, and I know where I have difficulty. I’m able to study those areas and make sure that I’m strong in those areas before the test.”

I asked the instructor to reflect on how he believed the clicker activities were affecting the students’ math anxiety. He stated, “I can see it helping. When you’re lecturing, there’s always going to be some students who shut down and go, okay, I don’t know. I’ll just let you finish. The clicker then offers the opportunity so students who may get dissuaded
from some topic, this gives them something to refocus their attention on so the class can restart at that moment.” The instructor added, “I think it causes a break in the format, and that gets it a bit more involved. I’m giving the students the ball. I take their input, so they’re actively being involved. It shifts the class to a more student-centered sort of thing rather than just, I’m at the board writing stuff, memorize this for an exam. It makes it a better culture. Overall, I think it improves their experience in the class.”

**Effect of clicker activities on mathematics self-efficacy**

All of the student interviews included a question about the effects of clickers on the students’ confidence in their math ability. Some responses were suggestive of a direct or immediate effect. Henry (Interview 1) claimed, “Clickers have given me a little bit of a confidence boost.” During the second interview, he stated, “It actually is giving me even more of a confidence boost as I do the problems and then see the solution on the board.” Hannah (Interview 2) remarked, “Sometimes when I get it wrong, I feel a bit frustrated. If I get it right, it helps me believe that I can actually do it.” She offered the following comments during the final interview: “With the clicker activities, I feel a bit insecure if my friends get it right and they, like, know how to approach the problem but not me.” Larry (Interview 3) stated that incorrect responses were “kind of disappointing.”

Several of the responses indicated the presence of an indirect effect of clickers on math self-efficacy via the identification of errors and topics to study when preparing for examinations. Henry (Interview 3) remarked, “It doesn’t have that direct effect, like, yeah, I’m awesome at this. However, it does help me realize what I need to study, go home and study it, and then come back and apply it.” During the last interview, he stated: “It’s very nice that I am able to get most of the questions right. If I get them wrong, I know where I’ve
gone wrong, so it has really helped me realize that I’m not as dumb as I thought I was at the beginning of the class.” Linda (Interview 4) expressed that the clicker activities provided “good feedback on what to study.” She added, “When I get a clicker question wrong, then I pay, like, super attention to the homework.” Hannah commented on the indirect impact of clickers during the third interview: “I don’t think it’s really a direct effect, but indirectly, from the clicker activities, I can know where I need to improve. From that, if I study on that topic, it actually improves my confidence level. It affects it indirectly.”

The calculus instructor shared his perspectives on how the clicker activities affected his students’ mathematics self-efficacy. He stated, “I think it helps them. It helps them evaluate where they’re at, especially if they’re consistently not landing with the rest of the class. It gives them the idea, maybe I should rethink how I approach things. If they’re getting it right, they’re like, okay, I’m getting it.” The instructor explained, “I try to make the clickers have, every so often, like, a little twist question to get them to think and probe into what’s going on. I want it to be a comfortable, you know, a safe kind of environment, but I also want to get them to think, to push their knowledge of math. I try to get them to self-reflect a bit more.”

**Immediate feedback provided by clickers**

Each of the four student interview protocols included a question about the immediate feedback provided by the clicker software. Some of the participants expressed that the feedback helped them identify errors and topics to study when preparing for examinations. Hannah remarked, “I think it is more helpful to get the immediate feedback because I can reflect and know about my strengths and weaknesses.” Henry (Interview 2) stated, “It lets me know that it’s something I need to study, especially with material that is on an upcoming
During the third interview, he stated: “It’s incredibly helpful to see the correct answer and then be able to go over it, as my professor does, and see what you did wrong.” Henry offered the following comments during the last interview: “It’s important to have the immediate feedback because the sooner you realize you have a problem, the more time you have to fix it.”

The interviewees discussed the effect of the immediate feedback on their math anxiety. Hannah (Interview 1) remarked, “It causes more anxiety if I answer incorrectly, like, if most of the students answered C but I chose D.” Her response during the second interview reflected a change in her perspective: “I previously felt nervous and lost confidence if I got it wrong, but I realized that it doesn’t matter. If I got it right, it helps me to feel more confident about myself.” According to Linda, “It definitely causes a little bit of anxiety if you don’t get it right, just because you know you did something wrong. If you thought you did it right, then that’s kind of a shock. If you have no idea how to do it, then you have some anxiety regardless of the actual answer.” Larry (Interview 3) stated, “I think it’s really helpful. They don’t really make me anxious. I guess they make me feel pretty comfortable since it is anonymous.” He offered the following comments during the final interview: “I guess I get a little bit anxious when I respond incorrectly, but not to a noticeable amount. I think the feedback is very useful.”

The calculus instructor discussed his perspectives on the immediate feedback he received via the clicker software. He stated, “That’s like – invaluable. Getting the immediate poll of students’ perceptions is really good. You can structure these questions and put, like, a deliberate trap answer of, like, there’s a logical fault with this line of reasoning. That will highlight misconceptions students have about certain topics. The immediate
feedback helps nip these in the bud and address these things quickly.” Speaking more
generally, he remarked, “It’s also very interesting to see what everyone’s thinking about.
You get some really interesting jumps from the first vote to the second vote.”

Anonymous responses to clicker questions

Each of the student interviews included a question about the anonymous feature of
the clicker responses. All of the participating students expressed that they felt more
comfortable knowing their responses to the questions were anonymous. Henry (Interview 1)
stated, “It’s an opportunity for me to learn instead of an opportunity for me to be almost
publicly chastised.” During the third interview, he said, “It’s helpful in the sense that your
teacher’s not pointing at you and asking, what did you get? That’s nerve-wracking. The fact
that you don’t have to stand up and say, I got this answer, and then people laugh if you got
the wrong answer, that’s definitely an added benefit.” According to Hannah, “I think that it’s
a very good thing, with the clickers, because I am very comfortable answering the questions.
Nobody will know what answer I respond to. No matter if it’s correct or not, it’s only me
that knows.” Larry remarked, “I guess they make me feel a little bit more comfortable, just
because I’m not raising my hand and speaking to the professor directly.” Linda shared the
following comments during the last interview: “It’s increased my comfort level. Yeah, if
your name was attached to it, it would be a little stressful. The histograms usually show
numerous people getting them wrong, so there’s not too much pressure even if I’m wrong.”

Some of the students described the sense of freedom they experienced when
responding to clicker questions because of the anonymity. According to Henry (Interview 2),
“It allows you to figure it out for yourself without being embarrassed. It really gives you the
freedom to kind of go your own way.” During the fourth interview, he stated, “With the
anonymity of the clickers, it’s really easy to put in the answer that you honestly think is the correct one, without any pressure of having it right or not. That’s a wonderful feature.”

Larry remarked, “I guess the anonymity kind of, just, helps us choose our own answer, instead of looking at other people to see if I’m agreeing.” Linda provided the following reflection on the anonymous feature of the clicker responses: “It’s better telling of your own ability. With the anonymous part of it, it’s more just for you and not for people’s perceptions of you.”

One of the interviewees suggested that she might be reluctant to answer the clicker questions if the responses were not anonymous. Linda (Interview 1) stated, “I’m glad that it’s confidential. If it had your name attached to it, that would make a lot of people shy away from answering.” During the third interview, she added: “If it wasn’t anonymous, when I wasn’t quite confident, I might not even submit a response because it is just a guess.” The calculus instructor provided the following comments on the anonymity provided by the clicker software: “I’m sure they like being anonymous. That takes pressure away from them. You don’t have to be right; you can just try it. Yeah, I think the anonymous feature of it is good.”

Most beneficial aspects of clicker activities

During each of the four rounds of student interviews, I asked the participants to reflect on what aspects of the clicker activities were most beneficial in supporting their learning of calculus. The participating students cited immediate feedback and anonymous responses as two of the most helpful aspects of using clickers, as described in the preceding sections. The students indicated that the immediate feedback helped them identify errors and determine the most effective way to allocate time when completing assignments and
preparing for examinations. The anonymous responses helped the students feel comfortable choosing the answer they believed to be correct, without fear of embarrassment if they voted for an incorrect response.

The students expressed that the increased classroom participation facilitated by the clickers was helpful. Hannah remarked, “I discuss it with my friends, and they tend to show me where I did something wrong.” Henry stated, “I believe that the clickers not only force me to engage with the lecture but engage with the people around me, and create those friendships in order to compete with each other.” Linda (Interview 1) said, “It forces me to actually work through problems on my own.” During the third interview, she stated, “I like it that you have to choose an answer to get any credit, so you have to try. Even if you just guess, you still have to look at the problem and vote for an answer.”

When asked about the aspects of clickers that were most beneficial, some of the interview participants mentioned the connection or relevance of the clicker questions to the math content they were learning and had to study when preparing for exams. Henry stated, “Another incredibly beneficial part is the relevance to what we’re learning. It provides reinforcement of, all right, this is an example of what we’re doing. You do it yourself and see what you come up with. I think that’s incredibly helpful.” Linda provided the following comments during the last interview: “I think the most beneficial thing about them is just, um, how connected they are to the exam. It’s like example test questions, which are pretty similar to the test.”

I asked the calculus instructor to reflect on what aspects of the clicker technology were most helpful in supporting his students’ learning of the course content. He responded, “I think it’s overall beneficial. It’s definitely increased student participation. There are a lot
of questions you can ask that have, sort of, misleading things. I just recently did the integral from minus infinity to infinity of sine of $x$ as a question. It’s quite thought provoking of what that’s actually supposed to equal.” The instructor added, “They offer you the chance to get students actively involved. I can prompt them to think about more conceptual things, more than just a rote kind of question.”

**Effect of clickers on attendance in the calculus course**

During each of the student interviews, I asked the participants to discuss what effect, if any, the clicker activities were having on their attendance in the class. The most common response was that the students would attend class regularly, even if their attendance were not recorded via the clickers. Henry remarked, “I would say that my attendance in the calculus class is already mandatory, and I go.” Across all four interviews, Hannah expressed that she would do her best to attend every lecture regardless of whether the instructor kept track of attendance. She stated (Interview 2), “If I miss one class, it will be hard for me to catch up.” During the final interview, she acknowledged that the clickers had motivated her to attend on some occasions: “In a way, like, if I wake up late, I will still try my best to come because of the clickers.” Linda stated, “I’d attend anyway, so it’s kind of, it doesn’t really matter to me, as far as my attendance. I would attend anyway.” During the final interview, Larry opined: “I guess they haven’t really made me come to class more just because I do have an interest in calculus. I mean, even if I wasn’t interested, I guess they would probably help me come to class so I could get the points.”

Some of the interviewees’ statements characterized clickers as a motivator or accountability tool, making their attendance in the class mandatory. Larry remarked, “I guess it kind of makes the course itself mandatory. I enjoy it, so I show up anyway.”
According to Linda, “It proves that I was there, and so getting points for attendance makes me want to be there more. I would definitely attend without them, but I like getting points for attendance.” Henry (Interview 2) stated, “It, of course, makes me get there because it’s an accountability tool, but I should really go because I need to learn this.” He provided the following reflection on the accountability aspect of clickers during the fourth interview: “It’s an accountability issue. I mean, if I don’t go to class, then that’s an easy ten percent of my grade that I’ve left on the table. It’s important to go to class, and it definitely encourages me to go to class.” The calculus instructor shared the following perspectives on the impact of clickers on his students’ attendance: “I think it’s improving it, or at least it’s better than it would be. Yeah, in terms of attendance, it seems to get the students to come to class.”

**Effect of clickers on achievement in mathematics**

Each of the student interview protocols included a question about the effect of clickers on math achievement. The participating students expressed that the clicker activities helped them identify errors and focus on specific topics to study for exams. Henry opined, “You immediately know if you’re doing it correctly or not. Evidence is a great tool, you know, I’m weak in this area. I’m gonna go home and study that.” Linda (Interview 1) stated, “With the feedback, you know exactly what you need to ask questions on.” She shared the following perspectives during the final interview: “It’s pretty accurate in reflecting the tests. Clickers have improved my understanding because, with the feedback, you can always see, this is exactly the situation and where I’m wrong. I need to study that later in order to get that concept for the exam.”

Some of the interviewees remarked that the clicker activities helped them prepare mentally for the exam scenario. Linda stated, “I think it helps because it’s like a daily quiz to
make sure that you’re on top of all the content that he’s presenting.” According to Hannah, “The clickers help me to prepare mentally for the tests. I learn from my mistakes with the immediate response.” Henry discussed the connection between the clicker activities and his exam preparation during the last interview: “I’d say that the clickers have allowed me to achieve the grade that I’m currently achieving, which is a B. Without the clickers, my exam prep would be inhibited, and my grade would probably be five to ten percent less.”

Among the interviewees initially identified as having low levels of math anxiety, another theme that emerged relates to the influence of clickers in helping them stay focused and engaged during lectures. According to Linda, “It makes sure that you’re focused in class because you have to be engaged with the lesson to understand the clicker problem. It kind of makes you, like, a little bit immune to the greater anxiety when it comes to the exams.” Larry (Interview 2) expressed that the clickers “really help us do better, just because of the interaction.” During the third interview, he stated: “I think that the interaction, just in general, with the class kind of helps me improve since it makes me think about the questions and not just copy it down.” Larry subsequently provided the following comments during the last interview: “I think they do help me focus more in class so that I can work on the problems and get it later.”

I asked the instructor for the course to consider how he felt the clickers were affecting his students’ achievement in the class. He stated, “Well, I’m trying to make it have a positive effect. It gets them actively involved in class. It seems like students, now, they have so much going on in their lives, so the chance they get to interact with mathematics outside of the classroom, that time window is getting smaller.” He added, “This offers a chance to get them actively engaged and get them to take some ownership of their math thought process. I
believe it is helping them overall, in terms of their achievement in the course.” When asked about the effect of clickers for students who have previously struggled with math, the instructor remarked, “I think it relieves some pressure and helps them, kind of, not check out. Maybe, in their previous math courses, it’s always been the lecture style. It gives them a chance to try it on their own, and if they’re very confident in it, they can share that confidence with other students.” The instructor provided the following perspectives regarding students who have struggled in math: “If they’re feeling a little uneasy, hopefully they are sitting next to supportive people. Getting stuff wrong is a huge part of learning mathematics. With no struggle, there’s no growth.”

**Pressure to respond correctly to clicker questions**

During each student interview, I asked the participant to consider the extent to which he or she felt pressured to respond correctly when working on the clicker problems in class. This question revealed confusion on the part of some students regarding the process through which the instructor graded the clicker responses. During the first half of the course, some of the students were under the impression that they would only receive credit for the clicker responses if they obtained the correct answer (i.e., they would receive a zero if they voted incorrectly) or expressed that they did not know how the instructor graded the clicker responses. I alerted the instructor to the confusion over the grading between the second and third rounds of interviews. He stated that the course syllabus specified that he was grading the clicker responses as a participation credit, and students would receive full credit as long as they voted for any answer. However, he acknowledged that he may not have clearly explained the grading process for the clickers when going over the syllabus during the first
lecture. He made two separate announcements in class to clarify the grading process after I called his attention to the confusion among some students.

During the second interview, Henry stated, “You want to get the right answer so you can get the points, but it still allows some freedom to get it wrong and then learn from that mistake.” He subsequently remarked, “The only pressure that I really have now is from myself and the people around me, especially since he made that announcement [clarifying the grading process].” Linda (Interview 2) expressed that it seemed “harsh” for students to receive a zero for the day if they made a mistake on a clicker problem. During the third interview, she stated: “Now that he explained it’s just graded for attendance, I still try and everything, but it’s a lot better.” Larry initially expressed that he did not know if the instructor based the clicker grades solely on participation or if the grades depended on selecting the correct answer. He later opined (Interview 3), “Now that I know that it’s not judged by, um, if you got the question right or not, I think that the pressure is a lot less. I can think calmly about the question and work through it.” Larry reflected on the pressure to respond correctly during the final interview: “I haven’t really felt much pressure except for, like, at the beginning of the semester because of, just, worrying about getting points off for choosing the wrong answer. Now that I know it’s just based on your attendance, it doesn’t really worry me too much.”

Aside from the grading process, another theme that emerged is that of intrinsic or internal pressure to obtain the correct answer to each clicker question. Henry remarked, “The most pressure I feel to choose the right answer is out of a personal competitiveness.” According to Larry, “As long as I understand it, that’s more my interest over, you know, getting a good grade. It does not discourage me as much as, kind of, motivating me.” Linda
(Interview 4) responded, “No external pressure; all internal. I want to be right. Just a little bit, if I’m wrong, it bugs me, and I’ll fix it.” During the third interview, Hannah stated: “Most of the time, I think seriously about getting the correct answer. I know it is just graded for attendance, but I really think carefully about each answer.” She provided the following comments during the fourth interview: “Well, of course, I will try my best to get the correct answer. It’s not that I take it lightly; I always try my best. It doesn’t really cause anxiety. I think it’s a good activity.”

I asked the instructor to describe the extent to which he believed his students felt pressured to obtain the correct response to the clicker problems. He explained, “I’m using it as a participation tool, so if they’re not coming to class, they’re losing the credit. If they come to class and they respond, they get the full credit for the day. Ten percent of the grade is based on the clickers.” The instructor added, “I feel like I’ve tried to do my best to get them to be as comfortable as possible and not worry about getting the right answer. I hope there is no pressure on them to get it correct. Certainly, in terms of how it impacts their grade, there’s none. I hope that they’re comfortable.”

Differences between classes with clickers and traditional lectures

I asked the student interviewees to consider how the calculus class would be different if the instructor did not use clickers to teach the course. The participants expressed that the clickers helped to increase their participation and engagement during lectures. Larry stated, “I see the clickers as beneficial in large classes. There is more interaction.” According to Linda, “You have to write it out and solve it as you would a question on an actual quiz, so it really motivates people to try things independently.” Henry (Interview 2) reflected on how the calculus class with clickers differed from his previous math courses: “I was very
disconnected with the math classes in high school because there was never really an engaging experience. I believe that the clickers help engage me in the class.” During the third interview, he stated: “If the clickers were gone, there might be other ways of having the students participate. However, I feel as though I’m much more engaged with the clickers. So the clickers, in my opinion, help immensely in my engagement with the class.”

The student interviewees reflected on how the class would be different without clickers. Hannah stated, “I think the environment would be so bland without the clickers. We would not interact, so I think clickers are a good thing during class because it makes me feel like I want to go to class. At times, you feel a bit bored when you just learn and listen.” Linda remarked, “I feel like I would zone out a little bit more without the clickers. I would be a little less engaged if he didn’t do it. I feel like people would be a little more laid-back if he didn’t use them, maybe a little less attendance.” Larry (Interview 3) said, “It would probably be more boring without the clickers. I wouldn’t be able to focus as easily. Without clickers, it wouldn’t be good for a large lecture hall.” He provided the following comments during the final interview: “I’d say using clickers is probably the best approach. I’ve taken other math classes without clickers, and I’ve fallen asleep a few times. I guess it helps me pay attention.” All of the participating students expressed that they would prefer to take future math courses using clickers, as opposed to the traditional lecture format.

I asked the calculus instructor to share his perspectives on the differences between clicker classes and previous courses he has taught without clickers. He stated, “I started using clickers last year for large lecture classes, and I’m not going back, definitely, for any large lecture class. You can’t just lecture for fifty minutes straight. You’re gonna slowly lose people. Getting them involved and getting them to interact is really important.” The
instructor added, “You get to play around with the trap answers and the immediate feedback, and you get to put the student response graph up, you know, it has more benefits. In terms of any class I teach that has a significant number of students like this, I will always use clickers or an equivalent technology.”

**Effect of clickers on enjoyment of the calculus course**

During each interview, I asked the students to reflect on their level of enthusiasm for the clicker activities and the effect of clickers on their enjoyment of the calculus course. The participants generally expressed that they enjoyed the lectures more with clickers. Henry expressed that the clickers “greatly impacted [his] enjoyment” of the course. When asked to elaborate, he stated, “It allows me to enjoy math, which is a rarity. I enjoy the people around me, and I enjoy competing with them. I enjoy math, and I largely attribute that to the clickers.” Larry remarked, “I guess they help me interact in class so that I can pay attention more and learn it. It helps me enjoy the class.”

Hannah (Interview 2) said, “I enjoy it because it is somewhat like a game for me. With clickers, I think I enjoy my math class more.” During the third interview, she commented on her enjoyment of the clicker activities in the context of the instructor’s clarification of the grading process: “I think I enjoy it more now that I know it is graded for participation rather than the correct answer.” Hannah provided the following reflection during the final interview: “I think clickers help me to enjoy the class more because we are required to, like, reflect with other students. I think it’s increased my enjoyment of the class.”

All of the participating students expressed that the clicker activities provided opportunities to socialize and interact with their classmates. According to Linda, “It makes
you socialize a little bit with your neighbors. I sit next to the same person every time, and we kind of compare answers. It’s usually a very brief conversation, but still a little bit of socializing.” Larry remarked, “It helps me interact in class, so the teacher can see how the class understands the concepts. I can talk to the people next to me just to see how they got the answer.” Hannah stated, “I enjoy using clickers because I can interact with my classmates. I can learn so much from my friends.” Henry (Interview 2) described how the clicker activities were helping him establish friendships with classmates: “As I grow to know the people around me, it’s a nice competition between us.” During the third interview, he said: “The clickers are a catalyst to help me meet the people around me. The people around me are the primary reason I enjoy the lectures so much. I feel much more comfortable working with the people I’ve met via the clickers.” Henry (Interview 4) remarked, “I look forward to the clicker questions because it’s fun to have that opportunity to chat with your buddies and talk about their method of solving the problems.”

**Effect of clickers on mathematical thought processes**

I asked the participating students to consider what effect the use of clickers had on their mathematical thought process during the calculus lectures. Both students initially identified as having high levels of math anxiety expressed that the clicker activities helped them structure their thought process when solving problems. According to Henry, “The clickers make me take a very solution-based approach to math. It has caused me to take a very, um, scientific way of approaching a problem, which has been very beneficial to me.” Hannah (Interview 2) stated, “It helps me to think accordingly, step-by-step, in order for me to reach the answer. I think it helps organize my thinking skills to solve math problems.” During the third interview, she remarked, “I can’t always think according to a structured
process, like the series of steps. From the lectures, I can learn to think accordingly, and I can ask my friend during the second part of the clickers. It’s kind of helpful in that way.”

Hannah provided the following reflection during the final interview: “It helps me to think according to, like, what is the first step I need to do, things like that. Sometimes I don’t know how to start or approach the question. After the clicker question, my professor will guide, like, how do we start the problem, so I can learn from that.”

Two of the participants emphasized the role of clickers in increasing their participation and engagement during lectures. Henry (Interview 1) stated, “Clickers allow me to take a very hands-on approach and own my own math education.” During the third interview, he remarked, “It keeps me engaged in class. Something my professor does that helps immensely is that he walks through the problem and, like, tells you why he’s doing certain things.” Linda (Interview 2) said, “You have to work through it on paper instead of just thinking about it.” She provided the following comments during the third interview: “I think I’m more engaged with the clickers. I just try to understand it, maybe a little more than I would if I wasn’t being quizzed on it the same day. I could procrastinate, like, oh, I can learn this later.”

When asked how the clicker activities impacted their mathematical thought process, the two students identified as having low math anxiety levels discussed how the clicker questions affected their preparation for examinations. Linda stated, “I just think about it as we’re learning it, instead of cramming before an exam. I still do a little bit of cramming, but that’s more, like, making sure I’m up to date with each lecture.” Larry (Interview 1) remarked, “It kind of puts pressure, you know, just trying to get it done before he stops the voting.” During the final interview, Larry said: “I guess, since I know that he doesn’t take
points, they don’t really make me anxious so that I have to get the right answer. Even if I get something wrong, I can see, okay, it’s similar to one of the answers, and then I can go back and see where I went wrong.”

**Instructor’s technique when using clickers**

With the exception of the first student interview, all of the interview protocols included a question about the instructor’s technique in using the clicker technology. All of the students I interviewed expressed that they were satisfied with the instructor’s use of the clickers. Linda remarked, “I think he’s doing well. I don’t know what changes I would suggest. I think he’s doing the best he can, and it works. I don’t know how he could make it better.” According to Hannah, “There’s no need for any changes because I like the way my instructor arranges the questions. I think it needs to be that way. First, we do it by ourselves, and then we discuss it.” Henry said, “I’m fully satisfied with the pace that he presents the clicker questions to us. It’s realistic for a test scenario.” Larry stated, “I think the clicker questions are at a pretty good amount. Not too many questions, but not too little interaction. It uses a lot of critical thinking. You kind of have to think outside the box.”

Three of the participating students discussed the time constraints of the fifty-minute lectures when commenting on the instructor’s technique in teaching calculus with clickers. According to Linda, “If he gave a little more time, that would be nice, but then I also understand why he can’t give too much time because it’s only a fifty-minute class.” Henry stated, “The only thing that I would change is that I would really like to add an extra ten minutes at the end of class to do another clicker question. It’s out of my professor’s control because we don’t have enough time.” Larry remarked, “I don’t think, at least for calculus,
you can really have more problems just because they take so much time, and there’s so much material to cover. With the time constraints, you can’t really do more.”

I asked the instructor to describe how he generally structured the clicker activities. He stated, “I have at least one question every day. I usually do four possible answers. They get the question, and I instruct them to work on it on their own. Then they vote, and then I ask them to talk to their friends.” The instructor added, “Most of them are sitting next to people they know, or they make new friends. Then they get a second chance to respond, and then I show them the poll, so the program will give an immediate listing of the percentages. So I show them the before and after.” The instructor’s description was fully consistent with the format of the clicker activities during the lectures I observed.

During the instructor interview, I also asked about the pedagogical changes that were necessary in order to accommodate the use of clickers when teaching the calculus course. He stated, “It’s an active thing, so you have to focus, you know, now it’s time for the students to engage with the material rather than passively listening to you.” The instructor remarked, “I think that’s what’s great about the clickers, especially in these large lecture classes, is that it really gives the students the opportunity to take some ownership of what’s going on, which is a good mentality to have when it comes to teaching mathematics.” He concluded, “You learn math by doing it, so the more active stuff, the better.”

**Effect of clickers on attitude toward learning mathematics**

During the third and fourth rounds of student interviews, I asked the participants to discuss the effect of the clicker activities on their overall attitude toward studying and learning mathematics. The most common response was that the clickers helped make the calculus course more enjoyable. Linda (Interview 3) stated, “I think it’s fun. I always sit
next to the same person, so we always confer with each other. Otherwise, I probably wouldn’t be talking to people, so it makes me talk to people during class. I feel better about math. It makes me feel happy.” Henry (Interview 3) said, “I still don’t get excited about going home and doing math problems, but they are kind of fun, so I would say that it’s improved my overall opinion of mathematics.” During the fourth interview, Henry remarked, “The use of clickers actually allows me to enjoy learning math and, you know, really own my own math education. I enjoy using the clickers in the way that the make me excited to learn and to try to answer them right.”

Hannah discussed the connection between the use of clickers and her exam preparation both times I asked about the effect of clickers on her attitude toward learning math. She said (Interview 3), “I feel like it decreases my anxiety in a way because when I have trouble with a particular question, I know it’s just practice. It’s not a big deal whether you get it wrong or right. I know the answer after that, so it actually trains me to do better on the test.” Hannah shared the following perspectives during the fourth interview: “It actually helps me to prepare for the situations I will be facing during the exam. It is a sudden, like, random question. That is almost the exact same thing I will have during the exams. I think that’s a good thing about clickers.”

Both of the interview participants initially identified as having low math anxiety levels discussed the helpful change in the lecture format facilitated by the clickers. During the third interview, Larry stated: “I guess I enjoy it already, so it’s not like it can really improve my attitude too much. It’s an interesting twist to the class.” He offered similar remarks during the last interview: “I guess they’ve probably helped me improve, even though I do already enjoy math. It’s an enjoyable process.” Linda (Interview 4) stated, “It helps
facilitate learning, I guess. It makes the class feel a little more modern too. It’s kind of like, we all have to do this clicker thing, so it’s just bonding with the rest of the class. I like it.”

**Perspectives on multiple choice format**

The second and fourth student interview protocols included questions about the interviewees’ opinions and perspectives on the multiple choice format of the clicker questions. Both of the high anxiety participants expressed that the multiple choice format helped them structure their thought process when responding to the clicker questions. Henry stated, “I believe the clickers are actually more helpful in multiple choice format. It helps give direction so you know which way to go in solving it.” According to Hannah (Interview 2), “I think the multiple choice format makes it more helpful. I am a learner who needs to get the big picture first before I go into details. I really need to think about what process will lead to this kind of answer.” During the fourth interview, she remarked, “I think it is more helpful to do it in multiple choice because I can structure my thinking to get the right answer.”

Most of the student interviewees discussed problems or issues that could potentially arise if the instructor presented the clicker questions using an open-ended format instead of multiple choice. Linda (Interview 2) stated, “I like that it’s multiple choice. If it was an open-ended question, I would be concerned about typing it in wrong because there’s so many variables.” She provided the following remarks during the last interview: “Realistically, I think that’s the only plausible way to do clicker questions and be accurate. He usually puts similar answers up there, so it is a good indicator. You can’t really guess on them and expect to get it right.”
According to Larry (Interview 2), “I think it’s more helpful in multiple choice. If you make a simple mistake, you know, like not pulling the negative sign down from equation to equation, it helps you see, oh, I made a mistake here, but I’m pretty sure that’s the answer.” During the final interview, he stated, “I think that it’s been more helpful because it’s just too broad of a spectrum with free response. I think that multiple choice is the easiest, and probably the best way.” Henry said, “I think the multiple choice is a good starting platform. It provides a baseline to let you know if you’re on the right track. With the clickers, I think that the multiple choice is actually a better way to go, as opposed to short answer.”

During the instructor interview, I asked about the benefits and constraints associated with the multiple choice format of the clicker activities. The instructor remarked, “When it comes to the quizzes and exams, those are open-ended. They have to provide written responses. It doesn’t line up with that, which is maybe a bit unfortunate. I like it for the in-class activity, especially because it gives you the numerical feedback of, this percent of you thought this was the right answer.” He added, “If it was open-ended, it might be harder to communicate that information in real time. Multiple choice math questions can get really fun. You can put misleading answers and play around with it, so the constraint of it being multiple choice forces you to get creative.”

**Clicker metaphors**

The final student interview protocol included the prompt, “Think of a metaphor to describe the role of clickers in your experience learning calculus this semester.” Henry responded, “The clicker is my flashlight, and math is a very dark woods. Without my flashlight, it would be very difficult to find my way.” Hannah provided a similar metaphor: “The clickers are like a lamp because it lights to show you the path, and a lamp provides the
light.” Larry stated, “Clickers are like a guide in the desert. The heat from the desert is kind of like a lot of stress to go through, but your guide kind of helps you go along from point A to point B.” Linda’s metaphor is thought provoking but quite different from the others: “Clickers are like a leprechaun because they’re tricky, but then if you know how to avoid the tricky, then you can get it right and move on with life. If not, then you learn from your mistakes and fix it. Then you approach the leprechaun again.”

Additional perspectives on clickers (instructor)

The protocol for the instructor interview included a question about comments and feedback the instructor had received from students related to the clickers. He stated, “Well, the students have not said much to me. I haven’t had any student complain about them. Anything a student has asked when it comes to clickers is usually something like, my clicker didn’t record my score today.” According to the instructor, “The only thing they really talk to me directly about, when it comes to clickers, is getting them to work. It might be a fun last day clicker question, did you like using clickers?”

I asked the calculus instructor to reflect on the extent to which clickers have helped him improve as an instructor. He responded, “I think it helps because it gives me a better way of structuring the fifty minutes. I can plan, like, after twenty minutes, I will present the clicker problem, and it offers a nice change in the format of the course so it’s not just me lecturing the whole time.” The instructor added, “I’ve been actively moving away from lecturing too much. I want to focus more on getting students actively involved. I think this is helping me succeed with my overall goal of eventually being as lecture-free as I possibly can.”
End of interview comments (clickers)

I concluded each interview by asking the participant if he or she had any additional comments or wanted to express any thoughts or opinions that were not covered by the interview questions. A few of the responses pertained to the effects of using clickers in the calculus class. Larry stated, “The clickers are pretty beneficial, just because I can interact in class. It helps me focus.” According to Henry, “Clickers, when they are used properly, they are a very effective educational tool. However, I believe that when used excessively, they can be a detriment to education. My professor does a great job of using the clickers.” Hannah (Interview 1) stated, “This is my first time experiencing the clickers, and at first I was worried. I thought it would be like a quiz every day, but I think it helps a lot.” She provided the following comments during the final interview: “Overall, I think clickers are a good thing. This is my first time experiencing the use of clickers in class, and I think it’s great to apply the technology.” The calculus instructor concluded the interview by stating, “I started using clickers last fall in a large class, giving them something where they have to at least get prompted to go, oh, I have to vote for an answer. I like it for the large lectures. I think it’s a great tool.”

Research Question 4: Student Perceptions of Relationships among Math Anxiety, Math Self-efficacy, and Achievement; Change in perceptions during semester; Differences between Students with Low and High Initial Math Anxiety Levels

The fourth research question sought to develop an understanding of the students’ perspectives on the relationships among math anxiety, mathematics self-efficacy, and achievement in math. In particular, I wanted to determine how the students’ perceptions
changed during the semester and analyze the differences between the responses of students initially identified as having high and low levels of math anxiety.

**Mathematics anxiety**

Each of the four interviews included a question that asked about participants’ levels of math anxiety at the time of the interview, as well as any changes to the students’ math anxiety levels. The levels of math anxiety described by the students in the first interview were generally consistent with the results of the MAS from the first survey. Hannah stated, “I think it’s quite severe. When I had my first exam, I was shaking, and I could not think.” Reflecting on past math courses, Henry responded, “I feel that my math anxiety is the primary reason I’ve struggled.” On the other hand, Larry remarked, “I guess usually I am not stressed out or anything. Sometimes I’ll get stuck on a problem, but I don’t get too stressed out about it.” Linda stated, “I usually prepare enough in advance where I feel comfortable.”

The interview participants initially classified as having low math anxiety consistently reported low math anxiety levels across the four interviews. Linda (Interview 4) stated, “I’m feeling pretty confident. If I continue as is, I’ll do fine. I don’t feel much stress. Just keep on doing what I’m doing.” Linda acknowledged that her math anxiety increased somewhat before the midterm examination but stated her anxiety decreased substantially after completing the midterm exam. During the fourth interview, Larry remarked: “I’d say that I’ve probably calmed down a bit. I was kind of nervous because it’s calculus. Now that I’m this far into the class, I’m pretty calm about it.”

The responses of the high anxiety students suggested more substantial changes in math anxiety, in comparison to the low anxiety students. Henry expressed an overall decrease in anxiety throughout the semester. During the final interview, he stated, “My
anxiety has gone down from the beginning of the semester. It’s no longer debilitating. I think that’s because I’m more prepared on the exams. I don’t feel completely lost, and that makes all the difference.” Hannah (Interview 4) described the changes in her math anxiety throughout the semester: “I started with quite severe anxiety because of my past experiences. Then I overcame it, but because of the results of the latest exam, I am not satisfied at all with my achievement. The anxiety does not increase as much as I had at the start of the class, so I think I can still improve.”

Mathematics self-efficacy

The low anxiety students consistently expressed strong confidence in their math ability across the interviews. During the first interview, Linda stated that she thought she was “pretty strong at mathematics.” She subsequently informed me (Interview 2) that she had received an “A” grade on the first exam, which is what she had predicted. Linda stated during Interview 3 that she had done very well on the midterm examination. She provided the following summary during the final interview: “I am very satisfied with my achievement in the calculus course. In the beginning, I thought I’d forget a lot over the summer, but pretty much everything has come back to me.” Larry also expressed strong math self-efficacy throughout the interviews, stating during the first two interviews that he was confident in his math ability. During the third interview, he stated, “I don’t think it’s really changed too much. I did pretty well on the midterm in comparison to the average, so I think that kind of boosted [my confidence].” Larry subsequently remarked (Interview 4), “I think I’ve done pretty well. I guess I would say I’m pretty satisfied. Doing well in calculus had kind of helped me think that I can do better. I think it’s probably helped me.”
The interviewees with high math anxiety initially described frustration over past experiences when asked about their confidence in math, but they expressed increased mathematics self-efficacy during later interviews. Hannah (Interview 1) stated that she had struggled in her most recent math course, which “totally downgraded [her] self-esteem in math. During the second interview, she remarked, “I got quite a good mark on my first exam. It actually helped me to build my confidence level.” Hannah continued to express increased confidence during the third interview: “After the midterm, I feel more confident in my math ability.” However, she expressed frustration during the final interview: “Well, at first, I was quite satisfied with my achievement. Along the way, I’ve found my weaknesses in some of the topics. I am not really satisfied with my achievement right now because my last exam did not go well.”

Henry also expressed frustration with previous experiences during the first interview, stating that he had previously failed the calculus course and was repeating the class. However, he expressed that he believed he was a “competent student in mathematics.” He indicated higher levels of self-efficacy in the subsequent interviews. During the second interview, Henry remarked, “My perception of my math knowledge has actually, I believe, increased, just because the first test went relatively well.” He subsequently stated (Interview 3), “It doesn’t come easily to me, but I do have the ability and the intelligence to do it.”

During the final interview, Henry reflected on the increase in his confidence: “Overall, I’m quite satisfied. I feel as though I’ve learned quite a bit this semester. I actually received an ‘A’ on the last exam. My perception of my ability, I think, has gotten greater because I think that my ability has gotten greater, especially in calculus.” I asked the instructor to describe
his level of satisfaction with his students’ achievement. He stated, “I would say I have been pretty pleased. As of late, especially, they’ve been doing quite well.”

**Effect of math anxiety on achievement in mathematics**

All of the student interview protocols included a question regarding the effects of math anxiety on achievement in mathematics. Based on the students’ responses, one of the consistent themes I identified is the presence of an optimal or ideal level of math anxiety. Students with excessive anxiety experience difficulty focusing on mathematics, especially during examinations. On the other hand, it is possible to have too little anxiety, which results in a lack of adequate exam preparation and reduced achievement. I believe the responses provided by Hannah are most indicative of this theme. During the first interview, Hannah stated, “I think it [anxiety] affects me a lot. It really disturbs me every time I take an exam, even a simple quiz.” She remarked (Interview 2), “The less anxiety I feel in math, it helps me to perform better. I need to control the math anxiety in order for me to achieve a good grade.”

Hannah reflected on her math anxiety during the third interview: “If the anxiety is out of my control or is very severe, it will really affect my grades. The anxiety I have now, I think it’s under my control, so it will not affect my grade too much.” Hannah’s summative reflection during the final interview was especially indicative of the existence of an ideal or optimal level of math anxiety. She stated, “Actually, I think I have had too little anxiety recently. I think that has made me feel a bit too comfortable, and I didn’t put in a lot of effort like I did before, so I think some anxiety is essential. I have had experiences where my anxiety was very severe, and I got bad results. Then, along the way, I had an appropriate amount of anxiety and did better. If I am too comfortable, I don’t put in the effort.”
Henry’s responses were also suggestive of an adverse effect on achievement when his math anxiety is elevated. During the first interview, he stated, “I could achieve, consistently, a full letter grade higher if I had [math anxiety] under control.” When I interviewed Henry the second time, he commented, “I am intimidated by math, so I believe it still affects my grade by a significant amount.” He later remarked (Interview 3), “My math anxiety still makes it hard to do the homework just because it seems daunting at first. It just makes it emotionally harder.” Henry provided the following reflection during the fourth interview: “It’s still daunting, um, to start an assignment. However, it has affected me less than in previous years because I feel as though I am actually learning the material.”

For the low anxiety participants, the primary theme I identified was that of mathematics anxiety as a motivator. When I asked him about the effect of math anxiety on his achievement in mathematics, Larry (Interview 1) stated, “It usually doesn’t hold me back at all. It mainly pushes me to try harder.” During the third interview, he remarked, “I think it [math anxiety] kind of pushes me farther to do well on the tests since it’s worth more points. It really helps me learn from my mistakes.” Larry provided the following comments during the final interview: “I guess the anxiety probably just pushed me to work harder. It hasn’t clouded my judgment or anything.” Linda (Interview 2) stated, “I think it [math anxiety] helps me work better, or work harder.” She reflected on the impact of her math anxiety during the last interview: “I don’t think my anxiety has affected me that much, except for giving me a little boost of energy to study. That’s always good, having a little bit of pressure on me, but not negatively.”

While interviewing the instructor, I asked him to consider what effect he believed mathematics anxiety had on his students’ achievement. He stated, “It probably affects it
quite a bit. I am teaching another class this semester, which is math for liberal arts. This is a
class that’s full of students who are very convinced that they’re not good at math. My
experience with them is that most of them can do mathematics, but somewhere along the
line, they got this anxiety, they got this fear that they’re not good at it.” The instructor added,
“This is my first time teaching that type of class, so it has really opened my eyes to how, just,
how bad it can be. Students that have very strong math talent are, you know, getting scared
of taking math.”

**Student perspectives on the instructor’s teaching style**

The second, third, and fourth student interview protocols included a question about
the participants’ general perspectives on the instructor’s technique in teaching the calculus
course. The phrasing of the question did not specifically reference clickers, although some of
the students’ responses included comments on the clicker activities. Linda (Interview 2)
expressed a positive opinion regarding the instructor: “On a scale from one to ten, I’d say
he’s doing a ten out of ten job.” During the third interview, she stated, “I think he’s doing a
great job. I think he’s structuring the class well.” Larry remarked, “I think that structurally,
it’s done pretty well since there’s that fifty minute timeline. We’re limited to that amount of
time, so I think he’s doing a good job.”

When prompted to consider changes the instructor could make to improve his
teaching, Henry responded, “The only thing he could really improve is to take more time out
of our day to teach us math. I thoroughly enjoy his lectures. I would like to do another
clicker question each day, but of course, in the constraints of the time that he has, it’s not
feasible.” According to Hannah (Interview 3), “My instructor organizes it well. He will
explain it or give a complete introduction for the questions, so he helps prepare us first.
Whether we actually understand it or not, we can actually reflect from the question. I think he does it well.” She reflected on the instructor’s teaching style during the final interview: “At first, I thought it would be better if he provided more time, but then, I think it is important to use the class time effectively. If we spend too much time with the clickers, it will take away from the lecture time.”

I asked the calculus instructor to discuss how he allocated the time during lectures, given the fact that he only had fifty minutes to present each day’s lecture. He responded, “I don’t think there’s too much of an issue with the time for me. I like the break in the format, and you can plan it to, kind of, cut the class into two parts. You can start off with an introduction of a new topic, some basic examples, and then say, okay, now let’s do a clicker problem.” The instructor added, “We can discuss it and then kind of build off of it. So, in terms of structuring it, it gives you an activity where you can build the before and after leading into this. I think, in terms of structuring it, the clickers are really helpful.”

**General effects of technology on college/university math instruction**

The final student interview protocol included a question about the general effects of modern technology on mathematics instruction in the college and university setting. Henry emphasized the importance of using technology appropriately in a given instructional context. He stated, “When utilized properly, technology is a great asset. I think that students can sometimes rely on it too much and not go into a professor’s office hours, which I think is a detriment to your learning. When utilized properly and in moderation, I think technology is a great asset to the university and college setting.” Hannah discussed the role of technology in providing guidance for students: “I think it’s way better because I use a graphing calculator to help me, and then the online homework, it is one of the things that helps me
study for the chapter. It also provides guidance when I answer the clicker questions, so I think the technology is really helpful.”

Linda reflected on the role technology can play in helping mathematics instructors structure class time. She remarked, “If you have, like, a PowerPoint, then it’s up to the students to copy down the examples. With clickers, it’s like, you need to do this, or you won’t get the points.” Linda also emphasized the importance of having a clear plan or agenda for each lecture: “Just having a plan or outline, in general, that’s good, whether it’s on paper or a PowerPoint. Working through example problems is really good, but you don’t really need any new technology to do that.” Larry expressed mixed feelings about the role of online homework in math courses: “The online homework, I guess I’m more of a pencil and paper person, so I’d prefer to just write it out, just because if I mistype something, I get points taken off. I guess that’s my opinion.”

**Additional perspectives (instructor)**

During the instructor interview, I asked about aspects of learning mathematics that cause difficulty for students. He remarked, “I think a lot of students have prior knowledge issues. Some of them, whatever they learned in high school might not exactly translate well to the college level, especially if they were not really taught process-oriented stuff, or they were more like, memorize these facts and regurgitate them.” The instructor expressed that many students appear to have misconceptions regarding the nature of mathematics. “I think that’s the biggest hindrance for students,” he concluded.

**End of interview comments (general)**

The final question during each interview was open-ended, asking the participant if he or she wanted to express additional comments or perspectives besides the responses to the
questions I asked. Larry stated, “I think the class is fun because the teacher makes it fun. The textbook covers situations that we won’t necessarily be tested on. If he could compile a list of book problems that are directly related to the exam, and just call it suggested book problems, that would be helpful. It’s kind of up to me to work hard at it.” Linda remarked, “I think he’s a good teacher. I think he’s doing very well. I’m feeling good about the class.” According to Hannah, “For the course in general, I think the time given to different topics is appropriate. It really fits with my pace.”
CHAPTER 5. DISCUSSION

This study sought to obtain a deeper understanding of the connections among the use of clickers, mathematics anxiety, math self-efficacy (students’ confidence in their own math ability), and achievement in mathematics among students who were enrolled in a large lecture, undergraduate calculus course during the Fall 2015 semester. The calculus instructor taught the class using clickers to present one or two questions each class period in a multiple-choice format. The students had two opportunities to vote for a response to each clicker question, first working individually and then discussing the problem with classmates. After the second vote, the instructor displayed histograms of each set of responses. Quantitative and qualitative research methods were used concurrently throughout the process of collecting and analyzing data. The participating students took two surveys during class time, the first near the beginning of the semester and the second near the end of the course. The final sample consisted of $N = 122$ students who took both surveys. Statistical methods were used to analyze the quantitative survey data.

Four students were selected to participate in a series of four audio recorded interviews based on gender and mathematics anxiety level, as determined by the results of the first survey. Qualitative methods were used to analyze the data obtained from the interview transcripts. Commonly used instruments, both of whose reliability and validity have been independently verified, were used to measure mathematics anxiety and math self-efficacy. The participating students’ final grades in the calculus course were used as the measure of achievement in mathematics. This study focused on the relationships between math anxiety, mathematics self-efficacy, and math achievement, along with the effects of clicker use on
these variables. In this chapter, I discuss the major conclusions of the study and explore implications for teaching and further research.

**Significance of the Study**

Prior to conducting this study, I was aware of only one previous study (Batchelor, 2015) that focused specifically on the relationship between the use of clicker technology and mathematics anxiety. This previous study employed exclusively a quantitative methodology comprised of a statistical analysis of survey responses. This dissertation study expanded on the previous study in several ways. First, this study incorporated statistical analysis of two additional variables: mathematics self-efficacy (measured by scores on the Mathematics Self-Efficacy Scale) and the students’ achievement in the calculus course (measured by final course grades). The data collection and analysis for this study also included a major qualitative component in which four students in an undergraduate calculus class were each interviewed four times during the semester to obtain data related to their perceptions of the course and how their perspectives changed during the semester. The calculus instructor was also interviewed. Because of the mixed methods approach and the inclusion of measures of mathematics self-efficacy and math achievement, this study helps to fill a gap in the literature and has the potential to inform additional research involving the use of clicker technology in mathematics courses.

**Conclusions**

The findings of this research yielded three conclusions. The first is related to previous literature, whereas the second and third are related to learning outcomes and math
anxiety. Each of the conclusions was achieved through a careful synthesis of the relevant quantitative and qualitative results.

**Current results confirmed relationships among math anxiety, mathematics self-efficacy, and math achievement**

The results of the statistical analysis were generally consistent with previous research. Based on the results of the bivariate correlation analysis procedure, the pairwise correlations among mathematics anxiety, math self-efficacy, and student achievement were consistent with previous findings. A significant positive correlation was found between math self-efficacy and achievement in mathematics, while significant negative correlations were obtained between math self-efficacy and mathematics anxiety and between math achievement and mathematics anxiety. The significant negative correlation between mathematics anxiety and math self-efficacy identified in this study was consistent with previous studies that found students with higher math anxiety levels tend to have decreased confidence in their mathematical ability (Akin & Kurbanoglu, 2011; Cooper & Robinson, 1991; Lyons & Beilock, 2012; May, 2009; Usher, 2009).

The factorial analysis of variance (ANOVA) procedure was used to determine the effect of demographic variables (gender, age, and race/ethnicity) on the participating students’ mathematics anxiety and math self-efficacy. While none of the demographic variables had a significant effect on the variation in the students’ math anxiety, race/ethnicity was found to have a significant effect on the variation in mathematics self-efficacy. In the demographic questionnaire (see Appendix D), the response choices for race/ethnicity were African American, Asian American, Hispanic/Latino, Native American, White (Caucasian), and “Other.” Students who identified as Hispanic/Latino were found to have higher levels of
mathematics self-efficacy in comparison with their classmates who identified as Asian American or selected “Other,” respectively. Participants who selected White (Caucasian) were found to be more confident in their math ability, compared to students who identified as Asian American or chose “Other,” respectively.

As discussed in Chapter 4, one must be careful to distinguish between statistical significance and practical significance when interpreting the significance of the effect of race/ethnicity on the variation in MSES scores. Three-quarters of the participating students identified as White (Caucasian). The number of students in the White (Caucasian) category was nearly ten times the number in the Asian American category, which had the second-highest percentage of students. Thus, the practical significance of the group differences by race/ethnicity is questionable, especially when the White (Caucasian) category is compared to other groups. In addition, the data for the “Other” category is difficult to interpret because this category may include students who identify as members of multiple racial/ethnic groups.

The relationships identified in the surveys were corroborated in the interview data. The student interviewees who were selected via the first survey as having high math anxiety expressed that they were least confident in their mathematical ability when their math anxiety was excessive. Conversely, the interview participants who initially identified as having low math anxiety consistently stated they were confident in their math ability and did not have much math anxiety across all interviews. A significant negative correlation was found between mathematics anxiety and math achievement. This finding was consistent with previous studies indicating that students with higher levels of math anxiety typically have reduced achievement in mathematics in comparison to their less anxious peers (Dew et al., 1984; Hembree, 1990). The interviewees identified as having high levels of math anxiety
indicated that excessive anxiety sometimes interfered with their achievement on examinations.

The results of this study revealed a significant positive correlation between mathematics self-efficacy and math achievement. This result was consistent with previous studies that found students with greater confidence in their mathematical ability tend to demonstrate higher levels of achievement in math (Hackett & Betz, 1989; Pajares & Kranzler, 1995). The student interviewees with high math anxiety levels expressed that their confidence in their math ability varied during the semester, with changes in math self-efficacy often occurring after an examination. None of the demographic variables tested had a significant effect on the variation in the students’ achievement in mathematics. When discussing correlation data, it is always important to note that the presence of a significant statistical correlation between two variables does not necessarily imply that a change in one variable causes a change in the other variable.

**Use of clickers can facilitate desired learning outcomes**

Clickers have the potential to promote desired learning outcomes when used effectively by students and instructors. This conclusion was based primarily on the interview data but is also supported by responses to questions about clicker use in the second survey administered near the end of the semester. The student interviewees consistently indicated that the clicker activities helped make the lectures more active and enjoyable. This result is consistent with previous findings that clickers help promote student engagement and a more enjoyable classroom environment for students in math courses (Bode et al., 2009; Bruff, 2009; Caldwell, 2007; Cline, 2006; D’Inverno et al., 2003; Gibson, 2011; Lock, 2011;
Retkute, 2009; Sharp, 2011; Strasser, 2010; Sun, 2014; Vaterlaus et al., 2012; Woelk, 2008).

All of the interview participants, including the calculus instructor, stated that they would prefer to use clickers in future math courses, as opposed to the traditional lecture format. During the end of semester survey, nearly three-quarters of the respondents chose “Strongly Agree” or “Agree” when asked if they participated in class more actively than they would have without the clickers. The remaining choices were “Undecided,” “Disagree,” and “Strongly Disagree.”

The four students who participated in the interviews often cited immediate feedback (via the histograms displayed on the projector screen) as one of the most beneficial aspects of the clicker activities. The interviewees expressed that the feedback helped them identify areas of strength and weakness, which in turn helped them determine what concepts and skills they needed to focus on when preparing for examinations. This finding is supported by previous research identifying immediate feedback as a helpful feature of using clickers in the classroom (Cline et al., 2008; McGivney & McGivney-Burelle, 2011; Serros et al., 2011), as well as studies showing that the use of clickers helps facilitate error analysis and guide students’ preparation for exams (D’Inverno et al., 2003; Robinson & King, 2009; Sharp, 2011).

The interview participants in this study indicated that the clicker activities during lectures helped them prepare mentally for the examination scenario, in which they had to solve a problem and respond within a limited amount of time. During the second survey, almost two-thirds of the participating students selected “Strongly Agree” or “Agree” when asked if the use of clickers helped them improve their understanding of calculus. Several previous studies indicated that clicker use is associated with stronger content knowledge and
achievement in mathematics (Gibson, 2011; Kolikant et al., 2010; Lim, 2011; Retkute, 2009; Shaffer & Collura, 2009; Strasser, 2010).

The results of the present study suggest that when used effectively, clickers have the potential to help reduce mathematics anxiety and increase math self-efficacy, especially for students who typically have significant math anxiety. The interview participants distinguished between the direct and indirect effects of clicker use on their math anxiety and mathematics self-efficacy. The direct or immediate effect occurs when a student learns whether her/his answer is correct. The student interviewees indicated that correct responses often led to feelings of relief and increased confidence, while incorrect responses sometimes caused them to worry or feel less confident in their knowledge of a particular topic. The indirect or long-term effect of clickers on math anxiety and self-efficacy involves identifying errors, improving study habits, and preparing mentally for the exam scenario.

The second survey included questions pertaining to the effect of clickers on students’ math self-efficacy and mathematics anxiety. When asked if the clicker activities helped them become more confident in their mathematical ability, over half of the students chose “Strongly Agree” or “Agree,” with one-third selecting “Undecided.” The responses to the survey question asking if clicker use helped students reduce their level of math anxiety were inconclusive, with “Undecided” being the most popular response. Perhaps the most encouraging aspect of the survey responses pertained to the following item: “I would encourage other math instructors to use clickers in their classes.” A strong majority (three-quarters) of participating students selected “Strongly Agree” or “Agree,” while only nine percent chose “Disagree” or “Strongly Disagree.”
A lack of mathematics anxiety may interfere with motivation and math achievement in some situations

The previous conclusions included references to the differing responses of interview participants who were initially selected as having high versus low levels of mathematics anxiety. The students identified as having high math anxiety indicated changes in their math anxiety level during the semester, largely as a result of their performance on examinations. However, the low anxiety participants consistently reported low levels of math anxiety across all four interviews. The interviewees who self-indicated as having high levels of mathematics anxiety expressed increased confidence when they scored well on exams and described feelings of frustration and diminished confidence after exams did not go well. On the other hand, the low anxiety participants expressed strong confidence in their mathematical ability across the four interviews.

The responses provided by the two interviewees initially identified as having high math anxiety levels suggested that in some situations, a lack of mathematics anxiety may demotivate students and result in decreased achievement. Excessive anxiety appears to interfere with math achievement, especially during in-class examinations, for students who struggle with math anxiety. However, some students who lack math anxiety may not prepare adequately for exams, potentially resulting in reduced achievement and an increase in math anxiety. In the present study, this phenomenon only occurred among the high anxiety participants. Statistically, the significant negative correlation between math anxiety and achievement in mathematics provides no quantitative evidence to support the need for mathematics anxiety as a motivator. The third conclusion is preliminary because it is based exclusively on the responses provided by two of the four interview participants. A more
precise analysis of the relationship between math anxiety and achievement is needed to clarify how the relationship differs between students who typically have high and low levels of math anxiety.

Existing research literature suggests that some students may require a minimal level of mathematics anxiety to stay motivated and achieve to their ability in math courses (Bong, Hwang, Noh, & Kim, 2014; Linder, Smart, & Cribbs, 2015; Necka, Sokolowski, & Lyons, 2015; Wang et al., 2015). For example, Necka et al. (2015) studied the relationship between mathematics anxiety and math achievement among first-year undergraduate students and found that some students with very low anxiety levels were demotivated to study for tests, resulting in decreased exam performance. External to math anxiety, previous research supports the role of anxiety as a motivator in general academic (Grinnell & Kyte, 1979; In’nami, 2006; Keeley, Zayac, & Correia, 2008), athletic (Robazza, Bortoli, & Hanin, 2006; Salminen, Liukkonen, Hanin, & Hyvönen, 1995), and music performance (Boucher & Ryan, 2011; Fullagar, Knight, & Sovern, 2013) contexts and settings.

Limitations

One of the primary limitations in the quantitative (statistical) analysis pertains to the fact that the final sample was comprised only of the students who took both in-class surveys. Since the second survey was administered after the host university’s deadline for official course withdrawal, students who officially dropped the course are not included in the data sample. In addition, any students who remained enrolled in the course but stopped attending lectures before the date of the second survey were also excluded from the sample. Of the 48 students who completed the first survey but did not take the second survey, approximately
half received no credit for the course. Specifically, 14 of these 48 students received a grade of “F,” while nine students officially withdrew from the course before the drop deadline. Among the 122 students in the final sample, only three students received a grade of “F,” and none of the students officially withdrew from the course.

Because the sample included only the students who finished the calculus course, a “survivor effect” was clearly present in the final course grade data and also likely present among other variables as well. This finding is consistent with previous studies that identified a “survivor effect” among participants in research in employment (Bridger, Brasher, & Dew, 2010; Osmotherly & Attia, 2006), medical (Edelstein, Kritz-Silverstein, & Barrett-Connor, 1998; Streiner, Patten, Anthony, & Cairney, 2009), and business management (Siggekow & Rivkin, 2009) contexts. I believe a self-selection bias may have also been present, especially among the interview participants.

The instructions for the surveys (both written and verbal) clearly stated that participation was voluntary, and students who lacked interest in the research topics may have declined to take the surveys. The interview participants were selected from the set of students who completed the first survey and checked a box indicating an interest in participating in the interviews. I believe the four students who completed the interviews were more likely enthusiastic about the course in comparison to students who did not express interest in the interview portion of the study. For the four subsample participants, it may also be possible that the students’ participation in the interviews could have affected their subsequent responses on the second survey.

During the process of synthesizing the results from the quantitative and qualitative data analysis, it became apparent that the student interview protocols did not contain a
question explicitly asking about the effect of math self-efficacy on achievement in mathematics. The quantitative analysis yielded a significant positive correlation between mathematics self-efficacy and math achievement, which was consistent with previous studies (Hackett & Betz, 1989; Pajares & Kranzler, 1995). Each of the four student interview protocols included a question specifically pertaining to the effect of math anxiety on achievement in mathematics. Although some interview participants discussed the relationship between their confidence in their math ability and their achievement in mathematics, the lack of an explicit question about this relationship in the student interview protocols may have represented a limitation of the present study.

Finally, the calculus instructor in this study was regarded as an excellent teacher by his students, and he was very enthusiastic about teaching mathematics with clickers. The interview participants consistently expressed that they were pleased with the instructor’s teaching style. In addition, the instructor appeared to have a positive rapport with the students during all of the observed lectures. When I interviewed the instructor, he expressed enthusiasm and enjoyment of the clicker activities, and the instructor’s enthusiasm for teaching math with clickers was apparent during the observed lectures. The results of this study may not generalize to other instructors, particularly if instructors dislike teaching with clickers or do not have a positive rapport with their students.

Proposed Mechanisms

Three mechanisms were proposed to explain the relationships among clicker use, mathematics self-efficacy, math anxiety, and achievement in mathematics (see Figure 2.1). Having synthesized the results of the quantitative and qualitative analysis, Mechanisms 1 and
3 appeared to be plausible, while Mechanism 2 was clearly not supported by the data. The quantitative survey results indicated a significant negative correlation between math anxiety and math self-efficacy, a significant positive correlation between math self-efficacy and achievement in mathematics, and a significant negative correlation between mathematics anxiety and math achievement. Based exclusively on the statistical correlations, all three of the proposed mechanisms initially appeared to be plausible.

While the statistical results appear to support all three of the proposed mechanisms to explain the relationships among the variables investigated in the present study, the interview data provide additional insights into the viability of each. Mechanism 2 was ruled out after due consideration of the qualitative data. Mechanism 2 hypothesized that the clicker activities would cause students to feel pressured to select the correct answer to each question, causing increased math anxiety and decreased math self-efficacy and, ultimately, resulting in a decrease in math achievement, as measured by the final grades in the calculus course. Based on the interview responses, there was no indication that the pressure to respond correctly to the clicker questions increased the participants’ overall math anxiety, decreased math self-efficacy on a long-term basis, or inhibited the students’ achievement in the class.

The remaining two mechanisms, Mechanism 1 and Mechanism 3, hypothesized that the use of clickers would lead to increased levels of math self-efficacy, decreased mathematics anxiety and, ultimately, to increased achievement in mathematics. In Mechanism 1, immediate feedback was the mediating variable through which clicker use was hypothesized to help decrease math anxiety and increase self-efficacy, leading to an increase in math achievement. The interview participants expressed that the immediate feedback facilitated by the use of clickers helped guide their study habits, identify errors, and prepare
for examinations, ultimately leading to increased math achievement. Since the pairwise statistical correlations among mathematics anxiety, math self-efficacy, and achievement in mathematics were consistent with all three proposed mechanisms, Mechanism 1 was found to be plausible.

Mechanism 3 was somewhat more complex and included increased participation and engagement during lectures, increased enjoyment of the course, and improved attendance as hypothesized mediating variables. The interview participants consistently expressed that they were more engaged and participated more actively during lectures than they would have without clickers. Likewise, the student interviewees indicated that they enjoyed the course more because of the clicker activities. With regard to attendance, the students generally indicated that they would attend class regularly even without clickers, although the clickers provided additional accountability and motivation to attend every lecture. Thus, Mechanism 3 was found to be plausible based on the quantitative and qualitative data. However, it is important to note that the finding of plausibility for Mechanisms 1 and 3 did not demonstrate causation between any specific variables.

**Implications for Teaching**

When teaching mathematics with clickers, an instructor needs to be willing to adjust her/his pedagogical techniques to adapt to the technology (Elicker & McConnell, 2011; Gray et al., 2012; McGivney & McGivney-Burelle, 2011; Titman & Lancaster, 2011). During the instructor interview, the calculus instructor discussed the challenges he experienced when using the clicker technology in a large lecture class but also expressed enjoyment of the process. The instructor’s care in structuring the clicker activities was apparent based on the
class observations, and the interview participants were generally pleased with the instructor’s technique in using the clickers. As with any form of instructional technology, the use of clickers in a mathematics course does not guarantee improved learning outcomes (Brosnan & Goodison, 2010; Gibson, 2011; Kolikant et al., 2010; Strasser, 2010). The results of the present study suggested that the calculus instructor used the clicker technology effectively in the calculus class. However, it is important for instructors to consider the implications of their pedagogical techniques when teaching math with clickers.

It is important for instructors to be clear in communicating the grading process to students when incorporating clickers in a mathematics course. In the present study, some of the interview participants expressed confusion regarding the grading process for the clicker activities during the first half of the semester. The confusion became apparent to me during the second round of interviews, with some students expressing concern about receiving a zero score for incorrect clicker responses and others believing they would receive full credit regardless of the answer chosen. I alerted the instructor to the confusion between the second round and third round of interviews. Although the course syllabus included a statement that the clicker responses were graded as a participation credit, with students receiving full credit as long as they voted for any response, the instructor acknowledged that he may not have discussed the grading process explicitly regarding clicker use during class time at the beginning of the semester. Thus, mathematics instructors teaching with clickers are encouraged to be as clear as possible in communicating the grading process to students.

In this study, the calculus instructor’s use of clickers during lectures was consistent with Mazur’s (2001) Peer Instruction (PI) framework for student interaction in the classroom. The students worked on each clicker problem individually for approximately five minutes
and voted for one of the answer choices. The instructor then asked the students to discuss the problem with classmates and vote again. Following the second poll, the calculus instructor displayed histograms indicating the respective percentages of students who voted for each answer choice during the two polls. Although the Peer Instruction framework can be used without clickers, previous studies have found this format helpful in facilitating clicker use in large lecture classes (Bruff, 2009; Cline et al., 2013; Gray, 2012; Lucas, 2009; McGivney & McGivney-Burelle, 2011). In this dissertation study, the interview participants expressed that the instructor’s chosen format for the clicker activities was helpful and enjoyable. Thus, I would encourage instructors to use a similar format when teaching mathematics with clickers, especially in large lecture courses.

**Implications for Future Research**

Data collection for the present study occurred in a large lecture calculus class with an enrollment limit of approximately 200 students. I would encourage other researchers to consider conducting similar studies in somewhat smaller classes, perhaps with an enrollment of approximately 100 students. In order to build on the knowledge gained from this study, I would also suggest studying the effects of using clickers in other kinds of math courses such as developmental mathematics, college algebra, or more advanced classes such as differential equations. In this study, three-quarters of the participating students identified as White (Caucasian). I recommend conducting a similar study in a class with students from a more diverse range of racial/ethnic backgrounds in order to develop a better understanding of the influence of students’ race/ethnicity on the relationships explored in this study.
The “survivor effect,” which resulted from the decision to include only the students who completed the calculus course in the research sample, represents a significant limitation of this study. The decision to include only the students who completed both surveys (pre and post) was made because the matched pairs of survey responses for individual students were essential given the chosen methodology for the statistical analysis. I believe a study of the effects of clicker use on math anxiety, math self-efficacy, and achievement in mathematics, in which all students who choose to participate at the beginning of a math course are included in the sample, would be very helpful in addressing this limitation. However, such a study would require a different statistical methodology to analyze the survey responses or other quantitative data, if the study incorporates a quantitative component. In addition, if this study were replicated, I would encourage the researcher to include a specific question about the impact of mathematics self-efficacy on math achievement as part of each student interview protocol.

Future studies could also explore the potential of clicker technology as a direct intervention, with the explicit goal of reducing mathematics anxiety, increasing students’ mathematics self-efficacy, and/or improving math achievement. For an intervention study, I would suggest including a comparison group that uses clickers in a common format such as the structure used by the calculus instructor in this study or in which the instructor does not use clickers at all when teaching the class. I believe it would be important for the instructor to explain to the students in the intervention group what specific goals (such as reducing math anxiety, increasing math self-efficacy, and/or improving achievement in mathematics) the intervention seeks to achieve.
In an intervention study, I would also encourage the instructor to include ongoing journal writing and individual student interviews in which the participants in the intervention group would reflect on their progress towards achieving the stated goals with the help of the clicker activities. This recommendation is based primarily on previous research indicating that journal writing (Braun, 2014; McNaught, 2010; Rogers, 2014) and student interviews (Edwards & Ruthven, 2003; Jenkins, 2010; Warshauer, 2015) can be used effectively by instructors as interventions to promote positive learning outcomes in mathematics courses. Furthermore, I believe interviews and journal writing would allow the researcher to gather narrative data to contextualize an intervention study.

Finally, I recommend additional research related to the conclusion that a lack of mathematics anxiety may demotivate students and result in decreased achievement in mathematics under some circumstances. Previous studies provide evidence that a minimal level of math anxiety is needed to motivate students to study and achieve to their potential in mathematics courses (Bong et al., 2014; Linder et al., 2015; Necka et al., 2015; Wang et al., 2015). In this study, however, the conclusion regarding the need for a minimal level of anxiety to motivate students to succeed is preliminary due to its dependence on the interview data from only two of the four respondents. Additional research is needed to explore how students’ levels of mathematics anxiety may differentially affect achievement in math depending on the students’ typical levels of math anxiety.

**Conclusion**

The pairwise statistical correlations among mathematics anxiety, math self-efficacy, and achievement in mathematics were all found to be consistent with previous research. The
results of this study suggest that, when used appropriately, clickers have the potential to help increase student engagement and participation in large lecture mathematics classes. In addition, effective use of clickers can potentially help to increase math achievement, reduce mathematics anxiety, and increase students’ confidence in their math ability. In some situations, a lack of mathematics anxiety may demotivate students and interfere with achievement in mathematics. Despite its limitations, I believe this dissertation study achieved its goal of providing a greater understanding of the connections among clicker use, math achievement, math anxiety, and mathematics self-efficacy. In addition, this study succeeded in filling a gap in the existing literature. It is my hope that this study will help guide math instructors who use clickers to teach large lecture classes and, additionally, inspire additional research on the benefits and limitations of clicker technology.
APPENDIX A. INSTITUTIONAL REVIEW BOARD APPROVAL

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Office for Responsible Research
Vice President for Research
1136 LeGum Hall
Ames, Iowa 50011-2107
515-294-4506
FAX 515-294-4517

Date: 5/15/2015

To: John Batchelor

CC: Dr. Anne Foegen
N1622 Lagomarcino Hall

From: Office for Responsible Research

Title: A Mixed Methods Study of the Effects of Clicker Use on Math Anxiety and Achievement in Mathematics

IRB ID: 15-276

Study Review Date: 5/15/2015

The project referenced above has been declared exempt from the requirements of the human subject protections regulations as described in 45 CFR 46.101(b) because it meets the following federal requirements for exemption:

• (1) Research conducted in established or commonly accepted education settings involving normal education practices, such as:
  • Research on regular and special education instructional strategies; or
  • Research on the effectiveness of, or the comparison among, instructional, curricular, or classroom management methods.

• (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures with adults or observation of public behavior where
  • Information obtained is recorded in such a manner that human subjects cannot be identified directly or through identifiers linked to the subjects; or
  • Any disclosure of the human subjects' responses outside the research could not reasonably place the subject at risk of criminal or civil liability or be damaging to their financial standing, employability, or reputation.

The determination of exemption means that:

• You do not need to submit an application for annual continuing review.

• You must carry out the research as described in the IRB application. Review by IRB staff is required prior to implementing modifications that may change the exempt status of the research. In general, review is required for any modifications to the research procedures (e.g., method of data collection, nature or scope of information to be collected, changes in confidentiality measures, etc.), modifications that result in the inclusion of participants from vulnerable populations, and/or any change that may increase the risk or discomfort to participants. Changes to key personnel must also be approved. The purpose of review is to determine if the project still meets the federal criteria for exemption.

Non-exempt research is subject to many regulatory requirements that must be addressed prior to implementation of the study. Conducting non-exempt research without IRB review and approval may constitute non-compliance with federal regulations and/or academic misconduct according to ISU policy.

Detailed Information about requirements for submission of modifications can be found on the Exempt Study Modification Form. A Personnel Change Form may be submitted when the only modification involves changes in study staff. If it is determined that exemption is no longer warranted, then an Application for Approval of Research Involving Humans Form will need to be submitted and approved before proceeding with data collection.

Please note that you must submit all research involving human participants for review. Only the IRB or designees may make the determination of exemption, even if you conduct a study in the future that is exactly like this study.

Please be aware that approval from other entities may also be needed. For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. An IRB determination of exemption in no way implies or guarantees that permission from these other entities will be granted.

Please don’t hesitate to contact us if you have questions or concerns at 515-294-4506 or IRB@iastate.edu.
APPENDIX B. MAS INSTRUMENT AND PERMISSION EMAIL

Mathematics Anxiety Scale

<table>
<thead>
<tr>
<th>Statement</th>
<th>Answer Choices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. It wouldn’t bother me at all to take more math courses.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>2. I have usually been at ease during math tests.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>3. I have usually been at ease in math courses.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>4. I usually don’t worry about my ability to solve math problems.</td>
<td>SD D U A SA</td>
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<td>5. I almost never get uptight while taking math tests.</td>
<td>SD D U A SA</td>
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<td>6. I get really uptight during math tests.</td>
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<tr>
<td>7. I get a sinking feeling when I think of trying hard math problems.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>8. My mind goes blank and I am unable to think clearly when working mathematics.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>9. Mathematics makes me feel uncomfortable and nervous.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>10. Mathematics makes me feel uneasy and confused.</td>
<td>SD D U A SA</td>
</tr>
</tbody>
</table>

*Note. SD = Strongly Disagree, D = Disagree, U = Undecided, A = Agree, SA = Strongly Agree.
The Mathematics Anxiety Scale is reprinted with permission of its author, Dr. Nancy E. Betz.*
John Batchelor <batchj@iastate.edu>

Copy of Research Article (Clickers and Math Anxiety) / Permission Request

batchj@iastate.edu <batchj@iastate.edu>

To: "Betz, Nancy" <nancy@iastate.edu>

Thu, Apr 3, 2014 at 10:38 PM

Dr. Betz,

Thank you so much for giving me permission to use the Mathematics Anxiety Scale in my upcoming dissertation research. I enjoyed using the Mathematics Anxiety Scale in my pre-dissertation study, and I look forward to using the MAS again in my dissertation research. Have a good day.

John Batchelor

John Batchelor
ISU Graduate Student
School of Education

On Thu, Apr 3, 2014 at 3:19 PM, Betz, Nancy <nancy@iastate.edu> wrote:

Sounds great!! yes I would be happy for you to use the Scale~!

Best wishes

From: batchj@iastate.edu [mailto:batchj@iastate.edu]
Sent: Friday, March 28, 2014 11:44 PM
To: Betz, Nancy
Subject: Copy of Research Article (Clickers and Math Anxiety) / Permission Request

Dr. Betz,

I recently completed the research report based on my pre-dissertation study of clicker use and math anxiety, in which I used the Mathematics Anxiety Scale (MAS) as the instrument to measure math anxiety. I have attached a copy of the research report to this email. Thank you for giving me permission to administer the Mathematics Anxiety Scale to the participants in my study and to reprint the MAS items in the research report.

https://mail.google.com/mail/u/0/?ui=2&ik=00fdde64cd&view=pt&search=sent&msg=14... 8/13/2015
For my upcoming dissertation research, I plan to conduct a mixed-methods study of clicker use and math anxiety involving surveys and student interviews. I would like to use the Mathematics Anxiety Scale again to measure math anxiety among the participants in my upcoming dissertation study. May I have permission to use the Mathematics Anxiety Scale in the survey instruments for my dissertation study and to reprint the MAS items in my dissertation? I presume this would be OK since you allowed me to use the Mathematics Anxiety Scale in my pre-dissertation study, but I want to make sure before I begin the dissertation study. Thank you for your consideration.

John Batchelor

----------------------------------------
John Batchelor
ISU Graduate Student
School of Education

On Thu, Jun 6, 2013 at 4:54 PM, Betz, Nancy <nancy.betz@isuedu> wrote:

Absolutely~!~! let me know what you find!!

best wishes, NB

Nancy E. Betz, Professor Emeritus
Department of Psychology
The Ohio State University
Columbus OH 43210

https://mail.google.com/mail/u/0/?ui=2&ik=00fde64cd&view=pt&search=sent&msg=14... 8/13/2015
From: batchj@iastate.edu [mailto:batchj@iastate.edu]
Sent: Wednesday, June 05, 2013 11:36 AM
To: Betz, Nancy
Subject: Permission Request

Dr. Betz,

I am a doctoral student in mathematics education at Iowa State University. I plan to conduct a pre-dissertation study to determine whether the use of classroom response systems ("clickers") affects the math anxiety levels of college students enrolled in an introductory calculus course during the upcoming fall semester. I am currently preparing the pre-intervention questionnaire that I will administer at the beginning of the semester. I recently read your 1978 article, "Prevalence, Distribution, and Correlates of Math Anxiety in College Students." Your article includes a list of ten questions that you modified from the Fennema-Sherman Mathematics Anxiety Scale to be more applicable to college students. I am requesting permission to include the ten questions from your article as part of the pre-intervention and post-intervention survey instruments for my study. I think the ten questions in Table 1 of your article would be ideal for my study of math anxiety and clicker use among college students. The pre-intervention survey will also include a demographic questionnaire concerning variables such as age, gender, and prior mathematics preparation. The post-intervention survey will include questions related to the students' attendance and actual use of the clickers throughout the semester. I would greatly appreciate your permission to include the questions about math anxiety that you included in your article. Please let me know if you have questions or would like additional information about my planned study. Thank you for your consideration.

Sincerely,

John Batchelor

-------------------------------
John Batchelor
ISU Graduate Student
School of Education

https://mail.google.com/mail/u/0/?ui=2&ik=00fdde64cd&view=pt&search=sent&msg=14... 8/13/2015
APPENDIX C. MSES SAMPLE ITEMS AND LICENSE

Mathematics Self-Efficacy Scale (Five Sample Items)

All of the MSES items are scored on a ten point Likert scale from 0 to 9:

<table>
<thead>
<tr>
<th>No Confidence at All</th>
<th>Very Little Confidence</th>
<th>Some Confidence</th>
<th>Much Confidence</th>
<th>Complete Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

Part I. How much confidence do you have that you could successfully:

7. Calculate recipe quantities for a dinner for 3 when the original recipe is for 12 people.

12. Compute your income taxes for the year.

18. Figure out how much lumber you need to buy in order to build a set of bookshelves.

Part II. Rate the following college courses according to how much confidence you have that you could complete the course with a final grade of “A” or “B.”

27. Geometry

33. Advanced Calculus

Note. The five sample MSES items are reprinted under license from the copyright holder, Mind Garden, Inc.
Mathematics Self-Efficacy Scale
Instrument and Scoring Guide

by
Nancy E. Betz
and
Gail Hackett

Published by Mind Garden, Inc.
info@mindgarden.com
www.mindgarden.com

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Copyright © 1993 Nancy E. Betz and Gail Hackett. All Rights Reserved.
To whom it may concern,

This letter is to grant permission for the above named person to use the following copyright material;

Instrument:  *Mathematics Self-Efficacy Scale*

Authors: *Nancy E. Betz & Gail Hackett*

Copyright: 1993 by Nancy E. Betz and Gail Hackett

for his/her thesis research.

Five sample items from this instrument may be reproduced for inclusion in a proposal, thesis, or dissertation.

The entire instrument may not be included or reproduced at any time in any other published material.

Sincerely,

[Signature]

Robert Most
Mind Garden, Inc.
www.mindgarden.com
APPENDIX D. SURVEY INSTRUMENTS (PRE AND POST)

Beginning of Course Survey (Page 1)

I. Please provide your name below. This information will be used to match your responses from this survey to the second survey near the end of the semester. All responses will be kept strictly confidential.

Name ________________________________________________________________________

II. Mathematics Anxiety Scale Items

Please respond to each statement by circling one of the answer choices for that item.

Note: SD = Strongly Disagree  D = Disagree  U = Undecided  A = Agree  SA = Strongly Agree

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Note: The Mathematics Anxiety Scale items above are reprinted, with permission, from Nancy E. Betz’s article, “Prevalence, Distribution, and Correlates of Math Anxiety in College Students.”
Beginning of Course Survey (Page 2)

III. Demographic Questions. (Skip any questions you do not wish to answer.)

1. Gender (Circle one):  Male    Female

2. Age (Circle one):  18-20  21-24  25-30  31-35  36-40  41 or older

3. Race/Ethnicity:
- White (Caucasian)
- African American
- Asian American
- Hispanic/Latino
- Native American
- Other

4. What math courses did you take in high school? (Check all that apply):
- Algebra I
- Algebra II
- Geometry
- Trigonometry
- Pre-Calculus
- Calculus
- Statistics
- Integrated Math I
- Integrated Math II
- Integrated Math III
- Integrated Math IV
- Other

5. How strong do you consider your math skills? (Check one)
- Very Weak
- Below Average
- Average
- Above Average
- Very Strong

6. What grade did you receive in your most recent math course?
- A
- B
- C
- D
- F

7. Across all types of classes, how much anxiety do you experience when taking tests?
- No Anxiety
- Mild Anxiety
- Moderate Anxiety
- Serious Anxiety
- Severe Anxiety
**End of Course Survey** (Page 1)

I. Please print your name below. This information will be used to match your responses from this survey to the previous survey. All responses will be kept strictly confidential.

   **Name**  
   ____________________________________________________

II. Mathematics Anxiety Scale Items

Please respond to each statement by circling one of the answer choices for that item.

   **Note:** SD = Strongly Disagree   D = Disagree   U = Undecided   A = Agree   SA = Strongly Agree

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</table>

   **Note:** The Mathematics Anxiety Scale items above are reprinted, with permission, from Nancy E. Betz’s article, “Prevalence, Distribution, and Correlates of Math Anxiety in College Students.”
III. Questions about clicker use.

Please respond to each statement by circling one of the answer choices for that item.

Note: SD = Strongly Disagree  D = Disagree  U = Undecided  A = Agree  SA = Strongly Agree

<table>
<thead>
<tr>
<th>Statement</th>
<th>Answer Choices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I have attended class more frequently than I would have if the instructor did not use clickers.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>2. I expect to earn a higher grade than I would have without using clickers.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>3. I have enjoyed the course more because of the clickers.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>4. The use of clickers has helped me improve my understanding of calculus concepts.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>5. I participated in class more actively than I would have without clickers.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>6. The clicker questions have helped me become more confident in my math ability.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>7. The use of clickers has helped to decrease my level of math anxiety.</td>
<td>SD D U A SA</td>
</tr>
<tr>
<td>8. I would encourage other math instructors to use clickers in their classes.</td>
<td>SD D U A SA</td>
</tr>
</tbody>
</table>

IV. Additional Questions.

1. To what extent have you found this course enjoyable?
   - [ ] Extremely enjoyable
   - [ ] Very enjoyable
   - [ ] Somewhat enjoyable
   - [ ] Slightly enjoyable
   - [ ] Not enjoyable at all

2. Approximately how many times have you been absent from this class?
   - [ ] 0-2 days
   - [ ] 3-5 days
   - [ ] 6-9 days
   - [ ] 10-15 days
   - [ ] 16 or more days

3. What grade do you expect to receive in this course?
   - A  B  C  D  F
APPENDIX E. INTERVIEW AND CLASSROOM OBSERVATION PROTOCOLS

Interview Protocol (First Student Interview)

1. How would you describe your mathematical ability?
   Follow-up: Rate math ability on scale from 1 to 5. How did you make this judgment?

2. To what extent have you been successful in your previous math courses?
   Follow-up: What grades have you received in previous math courses?

3. What grade do you expect to receive in your calculus class this semester?

4. How would you describe your level of math anxiety?
   Follow-up: Rate math anxiety on scale from 1 to 5. How did you make this judgment?

5. To what extent does your math anxiety affect your achievement in mathematics?

6. What aspects of learning mathematics cause you difficulty in your math courses?
   Examples: How instructor presents material, how textbook is organized, how course is structured

7. What aspects of the clicker activities are you finding most beneficial in supporting your learning?

8. Describe how the clicker activities are affecting your mathematical thinking and emotions during the calculus lectures.

9. Describe your perspectives on the immediate feedback the clickers provide. Is it helpful to know immediately if you voted for the correct response, or do you experience more anxiety when you answer a question incorrectly?

10. What effect, if any, do you expect the use of clickers to have on your level of math anxiety throughout the semester?

11. What effect do you anticipate that the clicker questions will have on your perception of your own mathematical ability throughout the semester?
12. Besides your calculus course, what other kinds of classes have you taken that involved the use of clickers?

13. What effect do you expect the use of clickers to have on your achievement in the calculus course?

14. How do you anticipate that clicker use will affect your overall enjoyment of the course?

15. Clickers allow you to respond to questions anonymously, without other students knowing what answer you choose. How do you think the anonymity of the clicker responses will affect your comfort level during lectures?

16. What effect do you anticipate the use of clickers will have on your attendance in the calculus class?

17. Besides clickers, what other forms of technology have you used in math courses? Examples: Online homework, interactive whiteboards, graphing software

18. How enthusiastic are you regarding the use of clickers in your calculus course?

19. To what extent do you feel pressured to choose the correct answer to each clicker question? Are you concerned that the clicker questions will affect your course grade?

20. Finally, do you have any other comments, or is there anything else you would like to add regarding the use of clickers in your calculus course?
Interview Protocol (Second Student Interview)

1. How has your perception of your math ability changed since the beginning of the course?
   Follow-up: Rate math ability on scale from 1 to 5. How did you make this judgment?

2. To what extent have the clicker questions affected your perception of your own mathematical ability?

3. How has your math anxiety level changed since the beginning of the course?
   Follow-up: Rate math anxiety on scale from 1 to 5. How did you make this judgment?

4. To what extent do you feel that your math anxiety is affecting or interfering with your achievement in the calculus class?

5. In what ways is your calculus class different from a class in which clickers are not used?

6. To what extent do you enjoy using clickers in your calculus course?

7. Describe ways in which the use of clickers helps to make the classroom environment more comfortable. Do the clicker questions cause any discomfort during lectures?

8. How is the use of clickers affecting your attendance in the calculus class?

9. What effect do the clicker activities have on your feelings and mathematical thinking during the calculus lectures?

10. How helpful is the immediate feedback that clickers provide? Is it helpful to know immediately if you voted for the correct response, or do you experience more anxiety when you answer a question incorrectly?

11. What aspects of the clicker activities do you find most helpful in supporting your learning of calculus?
   Examples: Immediate feedback, anonymity of responses, discussions with other students
12. How satisfied are you with the way your instructor allocates lecture time between presenting new material and asking clicker questions?

13. Clickers require the instructor to present the questions in a multiple-choice format. Do you feel that the clicker questions are helpful despite the restrictions on the question format?

14. To what extent is it helpful to be able to respond to the clicker questions anonymously, without other students knowing what answer you choose?

15. What effect do you feel that the clicker questions are having on your achievement in the calculus course?
   **Follow-up:** What grade do you expect to receive in the course?

16. How pleased are you with the frequency of the clicker questions and the amount of time you have to work on each question before voting for an answer?

17. How comfortable are you with the way your instructor structures the clicker activities? Would you recommend any changes to the format of the clicker questions?
   **Examples:** More time to work on problems, more or fewer questions per lecture

18. To what extent do you worry about choosing the correct answer to each clicker question? Do you worry about the effect of incorrect responses on your course grade?

19. How would you describe the effect of the clicker questions on your level of mathematics anxiety?

20. Finally, do you have any other comments, or is there anything else you would like to add regarding the use of clickers in your calculus course?
1. How has your perception of your math ability changed during the past few weeks?  
   Follow-up: Rate math ability on scale from 1 to 5. How did you make this judgment?  

2. How has your level of math anxiety changed during the past several weeks?  
   Follow-up: Rate math anxiety on scale from 1 to 5. How did you make this judgment?  

3. Describe how your math anxiety is affecting your achievement in the calculus course.  

4. How has your enjoyment of the clicker activities changed since the beginning of the semester?  

5. What aspects of the clicker activities are most helpful in supporting your learning of the calculus concepts?  
   Examples: Immediate feedback, anonymity of responses, discussions with other students  

6. How helpful is the immediate feedback that clickers provide regarding whether or not you chose the correct answer to a given question? Is it helpful to know immediately if you voted for the correct response, or do you experience more anxiety when you answer a question incorrectly?  

7. In what ways does the use of clickers affect your mathematics anxiety?  

8. To what extent are the clicker questions helping you improve your understanding of calculus?  

9. How are the clicker activities affecting your overall attitude toward learning mathematics?  

10. To what extent are you comfortable with the format of the clicker activities? Would you like to see any changes to the way your instructor structures the activities?  
    Examples: More time to work on problems, more or fewer questions per lecture  

11. How is clicker use affecting your attendance in the calculus class?
12. Describe the ways in which clicker use helps to make the classroom environment more comfortable. Do the clicker questions make you uncomfortable at times?

13. How would your calculus course be different if the instructor did not teach using clickers?

14. What grade do you expect to receive in the calculus course?

15. Describe the effect of the clicker questions on your perception of your own mathematical ability.

16. How helpful is it to be able to respond to the clicker questions anonymously, without other students knowing which response you choose?

17. How do you feel about the fairness and difficulty level of the clicker questions?

18. To what extent do you feel pressured to choose the correct answer to each clicker question? Are you concerned that you may receive a lower grade in the course if you do not answer the clicker questions correctly?

19. How are the clicker activities affecting your mathematical thinking and emotions during the calculus lectures?

20. Finally, do you have any other comments, or is there anything else you would like to add regarding the use of clickers in your calculus course?
Interview Protocol (Fourth Student Interview)

1. Overall, how satisfied are you with your achievement in the calculus course?
   Follow-up: What grade do you expect to receive in the course?

2. To what extent has your math anxiety affected your achievement in this course?

3. How would you describe your perception of your mathematical ability, compared to the beginning of the semester? 
   Follow-up: Rate math ability on scale from 1 to 5. How did you make this judgment?

4. How has the use of clickers in the calculus course affected your perception of your mathematical ability?

5. How has clicker use affected your level of math anxiety during the semester?

6. How has the use of clickers affected your attendance in the calculus class?

7. Clickers allow you to respond to questions anonymously, without other students knowing which response you choose. How has the anonymity of the clicker responses affected your comfort level during the calculus lectures?

8. Describe the effect that the clicker activities have had on your feelings and mathematical thinking during the calculus lectures this semester.

9. To what extent has clicker use helped you to improve your understanding of calculus?

10. What aspects of the clicker activities have been most beneficial in supporting your learning of calculus throughout the semester?
    Examples: Immediate feedback, anonymity of responses, discussions with other students

11. Describe your perspectives on the immediate feedback the clickers offer. Has it been helpful to know right away if you answered a question correctly, or did you experience more anxiety when you did not vote for the correct response?
12. Clickers require the instructor to present the questions in a multiple-choice format. Do you feel that the clicker questions have been valuable despite the limitations of the technology?

13. How has the use of clickers affected your overall enjoyment of the course?

14. To what extent have you felt pressured to choose the correct answer to each clicker question? Are you concerned that the clicker questions may affect your grade in a negative way?

15. How has the use of clickers in your calculus course affected your attitude toward learning mathematics?

16. Would you like to take additional mathematics courses using clickers, or would you prefer a traditional lecture approach in the future?

17. What changes could your instructor make to improve his teaching of calculus with clickers during future semesters? Examples: More time to work on problems, more or fewer questions per lecture

18. Describe how your level of math anxiety has changed during the semester. Follow-up: Rate math anxiety on scale from 1 to 5. How did you make this judgment?

19. To what extent do you believe clickers and other recent forms of technology have improved the teaching of mathematics in the university setting?

20. Think of a metaphor to describe the role of clickers in your experience learning calculus this semester.

21. Finally, do you have any other comments, or is there anything else you would like to add regarding the use of clickers in your calculus course?
Interview Protocol (Instructor Interview)

1. How long have you been teaching mathematics courses at the college or university level?
2. In general, how pleased are you with undergraduate students’ achievement in your math classes?
3. What aspects of learning mathematics cause students the most difficulty in college math courses?
   Examples: How instructor presents material, how textbook is organized, how course is structured
4. Describe how you structure the clicker activities in your calculus class.
5. To what extent do you feel that using clickers has helped you improve as an instructor?
6. What pedagogical changes do you have to make in order to accommodate clicker use in your teaching?
7. To what extent do you believe clickers are helpful for students who have learning disabilities or have struggled with math courses in the past?
8. To what extent does the use of clickers help make math courses more student-friendly or less intimidating for students?
9. Clicker software requires you to present the questions in a multiple-choice format. Do you feel uncomfortable or constrained by the multiple-choice format of the clicker questions?
10. What aspects of the clicker activities do you find most helpful in supporting your teaching of calculus?
    Examples: Immediate feedback, increased student participation, increased attendance
11. In your opinion, how much of an effect does mathematics anxiety have on students’ achievement in math courses?
12. How challenging is it to decide how to allocate lecture time between presenting new material and asking clicker questions?
13. What is your perspective on the effect of clickers on students’ math anxiety levels?
14. In your calculus class, do you count the students’ clicker responses as a component of their final grade in the course?

Follow-up: If so, what percentage of the course grade is based on the clicker responses?

15. Describe your perspectives on the immediate feedback that clickers provide. How helpful is it for you to know what percentage of the class voted for the correct answer to a clicker question?

16. To what extent are you concerned about your students worrying or feeling pressured to choose the correct response to every clicker question?

17. Clickers allow students to respond to questions anonymously, without their classmates knowing that answer they choose. How do you think the anonymity of the clicker responses affects your students’ comfort levels?

18. In what ways is your calculus class different from a class in which the instructor does not use clickers?

19. What effect do you anticipate that the clicker questions will have on your students’ perceptions of their own mathematical ability throughout the semester?

20. How effective are clickers in monitoring students’ attendance in your calculus class?

Follow-up: Do you believe clickers are helping to improve attendance in your class?

21. What effect do you expect the clickers to have on your students’ understanding of the course material and achievement / grades in the calculus course?

22. What kinds of comments have you received from past and/or current students regarding your use of clickers in class?

23. Do you plan to continue teaching with clickers during future semesters?

24. Finally, do you have any other comments, or is there anything else you would like to add regarding your experiences teaching calculus with clickers?
Class Observation Protocol

Date of Observation ______________________________

Lecture Topic ________________________________

Technology used besides clickers (e.g., document camera, graphing software)

Approximate Percentage of Seats Occupied (Attendance) ________

Clicker Question 1

Time Presented:

Topic of Question:

Number of Answer Choices:

Length of time to work on problem (individually) before first vote:

Length of time to work on problem (pairs / small groups) before second vote:

Percentage correct (first vote):

Percentage correct (second vote):

Does instructor explain solution to problem?

Other Notes (Clicker Question 1)
Clicker Question 2

Time Presented:

Topic of Question:

Number of Answer Choices:

Length of time to work on problem (individually) before first vote:

Length of time to work on problem (pairs / small groups) before second vote:

Percentage correct (first vote):

Percentage correct (second vote):

Does instructor explain solution to problem?

Other Notes (Clicker Question 2)

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Clicker Question 3

Time Presented:

Topic of Question:

Number of Answer Choices:

Length of time to work on problem (individually) before first vote:

Length of time to work on problem (pairs / small groups) before second vote:

Percentage correct (first vote):

Percentage correct (second vote):

Does instructor explain solution to problem?

Other Notes (Clicker Question 3)
APPENDIX F. CODING THEMES AND MATRICES

Preliminary List of Codes for Interview Transcripts

• Mastery Experiences
• Vicarious Experiences
• Verbal and Social Persuasions
• Emotional and Physiological States

• Effect of Math Anxiety on Math Achievement
  o Negative effect on achievement
  o Little or no effect on achievement

• Effect of Clicker Use on Thought Process during Lectures
  o Pay more attention in class
  o More actively engaged
  o Worrying about responses to clicker questions

• Helpful Aspects of Clicker Activities
  o Immediate feedback
  o Anonymity of responses
  o Discussions with other students

• Immediate Feedback
  o Mastery experiences – increased confidence after choosing correct response
  o Vicarious experiences – information about performance of other students
  o Effect of incorrect responses on math anxiety
  o Helpful to know if response is correct
  o Instructor’s response or adaptation based on percentage of correct responses

• Anticipation of Clicker Questions
  o Pay more attention during lectures
  o Take better notes
  o Effect on anxiety
• Effect of Clicker Use on Math Anxiety
  o Helpful to know if response is correct
  o Clickers provide form of test preparation
  o Fear of clicker responses affecting course grade
  o Pressure to choose correct response

• Effect of Clicker Use on Math Self-Efficacy
  o Increased confidence after correct response
  o Decreased confidence after incorrect response

• Format of Clicker Activities
  o Constraints of multiple-choice format
  o Incorrect responses help identify specific errors (error analysis)
  o Amount of time to work on problems
  o Number of clicker questions per lecture
  o Fairness, difficulty level of clicker questions

• Other Courses Involving Clicker Use
  o Other math courses (specify)
  o Other subjects (specify)

• Effect of Clicker Use on Math Achievement or Grade in Course
  o Helpful – Clicker use is improving grade
  o Helpful – Instructor’s response to immediate feedback
  o Helpful – Increased attendance
  o Helpful – Increased attention / participation / engagement
  o Helpful – Increased understanding of calculus concepts
  o Harmful – Clicker use is harming / lowering grade
  o Harmful – Worrying about choosing correct answer
  o Harmful – Worrying about effect on course grade

• Other Forms of Technology Used in Math Courses
  o Online homework
  o Interactive whiteboards
  o Graphing software
  o Tutorial software
  o Other (specify)
• Enjoyment of Clicker Activities
  o Enthusiasm – Looking forward to clicker questions
  o Effect of clicker use on overall enjoyment of calculus course

• Difficult Aspects of Learning Math
  o How instructor presents material
  o Textbook format
  o Structure of course

• Textbook Examples vs. Homework / Test Questions

• Anticipated Difficulty of Course

• Test Anxiety – Math vs. Other Courses

• Comfort Level with Course Content

• Importance of How Instructor Uses Clickers, Responds to Feedback

• Effect of Anonymous Responses on Comfort Level

• Effect of Clicker Use on Attendance

• Differences between Clicker Classes, Non-Clicker Classes

• Allocation of Class Time – Lecture vs. Clicker Activities

• Effect of Clicker Use on Overall Attitude toward Learning Math

• General Effects of Technology on Math Instruction
### Matrix Mapping Interview Question Topics across Four Interviews

<table>
<thead>
<tr>
<th>Topic</th>
<th>Subtopic</th>
<th>Interview 1</th>
<th>Interview 2</th>
<th>Interview 3</th>
<th>Interview 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clickers</strong></td>
<td>Additional Classes Using Clickers</td>
<td>Question 12</td>
<td></td>
<td></td>
<td>Question 16</td>
</tr>
<tr>
<td></td>
<td>Effect on Enjoyment of Course</td>
<td>Question 14</td>
<td>Question 6</td>
<td>Question 4</td>
<td>Question 13</td>
</tr>
<tr>
<td></td>
<td>Enthusiasm re: Clicker Use</td>
<td>Question 18</td>
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<td></td>
<td>Pressure of Grading</td>
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<td>Question 18</td>
<td>Question 18</td>
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<td>Effect on Attendance</td>
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<td>Question 8</td>
<td>Question 11</td>
<td>Question 6</td>
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<td>Immediate Feedback</td>
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<td>Question 6</td>
<td>Question 11</td>
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<td></td>
<td>Effect on Attitude re: Mathematics</td>
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<td>Question 9</td>
<td>Question 15</td>
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<tr>
<td></td>
<td>Aspects of Clicker Use that Support Learning</td>
<td>Question 7</td>
<td>Question 11</td>
<td>Question 5</td>
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<tr>
<td></td>
<td>Effect of Clicker Activities on Thought Process</td>
<td>Question 8</td>
<td>Question 9</td>
<td>Question 19</td>
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<td>Anonymous Responses to Questions</td>
<td>Question 15</td>
<td>Question 14</td>
<td>Question 16</td>
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<tr>
<td></td>
<td>Comfort / Discomfort of Classroom Environment</td>
<td></td>
<td></td>
<td>Question 7</td>
<td>Question 12</td>
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<td>Frequency of Clicker Questions</td>
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<td><strong>Clickers → Pedagogical Changes</strong></td>
<td>Differences between Clicker, Non-Clicker Classes</td>
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<td>Question 13</td>
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<td></td>
<td>Changes Instructor Could Make</td>
<td>Question 17</td>
<td>Question 10</td>
<td>Question 10</td>
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<td>Fairness, Format of Clicker Questions</td>
<td>Question 13</td>
<td>Question 17</td>
<td>Question 12</td>
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<td></td>
<td>Allocation of Lecture Time</td>
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<td>Question 12</td>
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<tr>
<td><strong>Clickers → Mathematics Anxiety</strong></td>
<td></td>
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<td>Question 19</td>
<td>Question 7</td>
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<td>Topic</td>
<td>Subtopic</td>
<td>Interview 1</td>
<td>Interview 2</td>
<td>Interview 3</td>
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<td><strong>Clickers → Mathematics Achievement</strong></td>
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<td>Question 2</td>
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<td><strong>Mathematics Achievement</strong></td>
<td>Previous Math Courses</td>
<td>Question 2</td>
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<tr>
<td></td>
<td>Expected Grade in Calculus Course</td>
<td>Question 3</td>
<td>Question 14</td>
<td>Question 1</td>
<td></td>
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<tr>
<td><strong>Instructional Technology</strong></td>
<td>Other Technology besides Clickers</td>
<td>Question 17</td>
<td></td>
<td>Question 19</td>
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<tr>
<td><strong>Metaphor Question</strong></td>
<td>Role of Clickers in Experience Learning Calculus</td>
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<td>Question 20</td>
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<td><strong>Other Comments</strong></td>
<td></td>
<td>Question 20</td>
<td>Question 20</td>
<td>Question 20</td>
<td>Question 21</td>
</tr>
</tbody>
</table>
Second Cycle Coding Matrix (Sample Pages)

Interview Participants
Larry – Male, Low Math Anxiety
Henry – Male, High Math Anxiety
Linda – Female, Low Math Anxiety
Hannah – Female, High Math Anxiety
Instructor – Calculus Course Instructor
Note: All student names are pseudonyms.

<table>
<thead>
<tr>
<th>Sociological Codes (from Literature)</th>
<th>“En Vivo” Codes</th>
<th>Sample Quotations from Interview Transcripts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics Anxiety</td>
<td>Quite severe, I was shaking, usually I am not stressed out, feeling pretty confident, don’t feel much stress</td>
<td>“I think it’s quite severe. When I had my first exam, I was shaking, and I could not think.” – Hannah, Int. 1</td>
</tr>
<tr>
<td></td>
<td>Anxiety has gone down a little bit, reduced, don’t think it’s really changed, anxiety has gone down significantly, anxiety has increased, don’t think it’s really increased, I’ve probably calmed down a bit</td>
<td>“I guess usually I am not stressed out or anything. Sometimes I’ll get stuck on a problem, but I don’t get too stressed out about it.” – Larry, Int. 1</td>
</tr>
<tr>
<td></td>
<td>Anxiety Levels at Specific Times</td>
<td>“Now that it’s the end of the semester, and I’ve had three exams to judge, like, where I typically place, I’m feeling pretty confident. If I continue as is, I’ll do fine. I don’t feel much stress. Just keep on doing what I’m doing.” – Linda, Int. 4</td>
</tr>
<tr>
<td></td>
<td>Change (or Lack of Change) in Math Anxiety</td>
<td>“I would say that my math anxiety, in class at least, has gone down a little bit.” – Henry, Int. 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“I think my math anxiety has been reduced. You know, I have gained some confidence throughout my studies.” – Hannah, Int. 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“I don’t think it’s really changed at all. It just pushes me to try harder.” – Larry, Int. 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“I feel quite prepared and knowledgeable of our current area of study, so my math anxiety has gone down significantly.” – Henry, Int. 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“I think the anxiety has increased because of the topic [limits]. Whenever I don’t understand a particular topic, I feel that anxiety. I feel scared if I don’t know it well for an upcoming exam.” – Hannah, Int. 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“I don’t think it’s really increased at all.” – Larry, Int. 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Since we’re almost done with the semester, I’d say that I’ve probably calmed down a bit. I was kind of nervous because it’s calculus. Now that I’m this far into the class, I’m pretty calm about it.” – Larry, Int. 4</td>
</tr>
</tbody>
</table>
## Mathematics Anxiety

Math anxiety is the primary reason I’ve struggled, usually prepare enough in advance, midterm is coming up, not very nervous after the midterm, more prepared on the exams, don’t feel completely lost, I overcame anxiety

<table>
<thead>
<tr>
<th>Sociological Codes (from Literature)</th>
<th>“En Vivo” Codes</th>
<th>Sample Quotations from Interview Transcripts</th>
<th>Connection to Other Variables / Factors</th>
</tr>
</thead>
</table>
| Mathematics Anxiety                 | Math anxiety is the primary reason I’ve struggled, usually prepare enough in advance, midterm is coming up, not very nervous after the midterm, more prepared on the exams, don’t feel completely lost, I overcame anxiety | “I feel my math anxiety is the primary reason I’ve struggled.” – Henry, Int. 1  
“I usually prepare enough in advance where I feel comfortable.” – Linda, Int. 1  
“The midterm is coming up, and he says that different teachers are going to be writing it. I don’t know how I’m going to be doing in comparison to other teachers’ style.” – Linda, Int. 2  
“Right before the midterm, I, like, went crazy with flashcards, and then I was making sure that I wasn’t gonna forget, like, the smallest things. After the midterm, then I was like, now I don’t have a test for a while, so I was not very nervous.” – Linda, Int. 3  
“My anxiety has gone down from the beginning of the semester. It’s no longer debilitating. I think that’s because I’m more prepared on the exams. I don’t feel completely lost, and that makes all the difference.” – Henry, Int. 4  
“I started with quite severe anxiety because of my past experiences. Then I overcame it, but because of the results of the latest exam, I am not satisfied at all with my achievement. The anxiety does not increase as much as I had at the start of the class, so I think I can still improve.” – Hannah, Int. 1 | |

## Math Self-Efficacy

Competent student, pretty strong at mathematics, I got an A, very satisfied with my achievement, I’ve done pretty well

<table>
<thead>
<tr>
<th>Math Self-Efficacy (Perception of Math Ability)</th>
<th>Math Self-Efficacy at Specific Times</th>
<th>Change (or Lack of Change) in Self-Efficacy</th>
</tr>
</thead>
</table>
| Competent student, pretty strong at mathematics, I got an A, very satisfied with my achievement, I’ve done pretty well | “I’m a competent student in mathematics.” – Henry, Int. 1  
“I am pretty strong at mathematics.” – Linda, Int. 1  
“Well, we had the one test, and I got an A on it, so I guess it hasn’t changed that much because I predicted I would get an A.” – Linda, Int. 2  
“I am very satisfied with my achievement in the calculus course. In the beginning, I thought I’d forget a lot over the summer, but pretty much everything has come back to me.” – Linda, Int. 4  
“I think I’ve done pretty well. I guess I would say I’m pretty satisfied. Doing well in calculus has kind of helped me think that I can do better. I think it’s probably helped me.” – Larry, Int. 4 | Struggled in previous math course; “It totally downgraded my self-esteem in math.” – Hannah, Int. 1  
“My perception of my math knowledge has actually, I believe, increased, just because the first test went relatively well.” – Henry, Int. 2 |
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</table>
| Math Self-Efficacy (Perception of Math Ability) | think it’s really changed, perception of ability has gotten greater | “I feel slightly better. I did better on the midterm than I did on the previous test, so I guess it’s improving.” – Linda, Int. 3  
“I don’t think it’s really changed too much. I did pretty well on the midterm in comparison to the average, so I thought that kind of boosted it.” – Larry, Int. 3  
“Overall, I’m quite satisfied. I feel as though I’ve learned quite a bit this semester. I actually received an A on the last exam. My perception of my ability, I think, has gotten greater because I think that my ability has gotten greater, especially in calculus.” – Henry, Int. 4  
“Well, at first, I was quite satisfied with my achievement. Along the way, I’ve found my weaknesses in some of the topics. I am not really satisfied with my achievement right now because my last exam did not go well. I think there is still room to improve. I just need to put in more effort like I did in the earlier exams.” – Hannah, Int. 4 |
| Instructor’s Perception of Student Achievement | | **Connection to Other Variables / Factors**  
“Good mark on first exam helped build confidence, I have the ability and intelligence, feel more confident after midterm, depends on the topic”  
| | “I would say I have been pretty pleased. As of late, especially, they’ve been doing quite well. That’s been more of a reflection, I’ve been adapting and changing some of my teaching methods. Recently, I’m happier than I was when I first started.” – Instructor |


REFERENCES


