ABSTRACT

TOWNSEND, MEGAN CARPENTER. Computer Technology, Student Achievement, and Equity: A Multilevel Analysis of the Relationship between High School Students' Use of Computers, Gender, and Mathematics Achievement. (Under the direction of Dr. Tamara V. Young and Dr. Lori B. Holcomb.)

The level of access that teachers and students in American public schools have to computer technology has grown dramatically in the last two decades. Despite widespread access to technology in schools, the evidence linking technology to student achievement is inconclusive. Numerous studies have identified positive, negative, and neutral relationships between technology use and student achievement. Further, there is little research on the role gender plays in the relationship between the use of technology in instruction and student achievement. This study utilizes data from the Education Longitudinal Study of 2002 to investigate the relationship between teachers' participation in professional development in technology, the use of computer technology in mathematics classes, and student achievement in mathematics. The purpose of this study is not only to examine the extent to which computer technology is related to math achievement after controlling for potentially confounding variables, but also to explain the extent to which computer technology use in the classroom correlates similarly with achievement for male and female students.

This study has several notable findings. First, students of teachers who participated in professional development were more likely to use computers in the classroom than students of teachers who did not participate in professional development. Students of teachers who participated in training in software applications, integrating technology, and advanced training were more likely to use computers in the classroom compared to students

of teachers who did not participate in these trainings. Second, the use of computers in the classroom was negatively related to student achievement. An analysis of the specific applications of computers revealed that the use of computers to review math work was negatively related to student achievement, and the use of computers to apply learning was positively related to student achievement. Finally, there were interaction effects between gender and the use of computers to instruct one-on-one, and gender and the use of computers at home. These findings suggest that professional development on the use of technology can encourage technology use in the classroom, the relationship between computer use in instruction and achievement varies, depending on the manner in which computers are used, and there are some gender differences in the relationship between computer use and achievement.

Computer Technology, Student Achievement, and Equity: A Multilevel Analysis of the Relationship between High School Students' Use of Computers, Gender, and Mathematics Achievement

by
Megan Carpenter Townsend

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APPROVED BY:

Dr. Tamara V. Young Committee Co-chair	Dr. Lori B. Holcomb Committee Co-chair
Dr. Kevin P. Brady	Dr. Matthew Militello

DEDICATION

To Mom, Dad, Eric, Madeleine, and Violet

BIOGRAPHY

I grew up in and around Raleigh, North Carolina. As a child, I displayed questionable talent for numerous extra-curricular activities. As a soccer star, I am probably best known for standing still for an entire game. I also took dance, piano, and violin lessons for several years, but those performances were nothing to speak of – unless you count dancing to "Good Vibrations" (the Marky Mark version, of course) in a neon bodysuit.

I began my career as a lifelong student in the engineering department at North Carolina State University (NCSU). I was quickly encouraged to become a multi-disciplinary "scholar" and joined the Benjamin Franklin Scholars program. It was in my second computer programming class that I met my husband, Eric, although it was a few years before we realized our undying love for each other. After graduating with degrees in computer engineering and science, technology, and society, I still wanted more education. I completed the masters program at NCSU in industrial engineering and decided seven years was plenty of time to be in college, so I bid adieu to NCSU and sought out gainful employment. But within two years, I returned to NCSU for a Ph.D. in educational research and policy analysis.

When I am not writing dissertations, I enjoy spending time with my family, reading, playing video games, and watching science fiction.

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CHAPTER 1

Introduction

Overview

At a high school somewhere in the United States, students are using computers to run simulations in their mathematics class. The computers facilitate their knowledge and allow them to explore how that knowledge can be applied to different scenarios. Students are given direction as to what to do, but also have the freedom to design their own simulations. In short, students are free to play with computer technology to enhance their understanding of mathematical concepts. Students are engaged and on-task.

At another high school, students are instructed to use computers to access a website to work mathematical problems. They are told that they should use their textbook and their notes for reference. Some students pull out a calculator, as well. Students begin working problems online as the teacher rotates around the room to answer questions and provide assistance. A few minutes into the activity, a handful of students login to Facebook. Another student accesses an Anime website. Other students start talking about their plans for the weekend. Several minutes later, about half of the students in the class have finished working problems. The rest of the students are surfing the Internet or chatting.

These are just two examples of the manner in which computer technology is being used in classrooms across the country. Technology is quickly becoming ubiquitous in schools (Gray & Lewis, 2009). With the expanding presence of technology in education, it is important to understand the relationship between the use of technology and measures of student outcomes, namely student achievement. Furthermore, purchasing, implementing, and maintaining technology is not an inexpensive endeavor, and understanding how various uses of technology are related to student achievement may contribute to more effective methods of implementation. If technology is just the latest in a long line of failed education reforms (Bianchi, 2004; Cuban, 2001; Cuban, 2006; Vascellaro, 2006), those funds could be better spent on other projects or initiatives. Conversely, if technology is the tool that will close the digital divide, improve student outcomes, and prepare students for a technology-saturated world (Gray et al., 2001; Edwards, 2003; Stallard & Cocker, 2001; Swain & Pearson, 2003), it is worth investigating the most effective ways of utilizing that technology.

The level of access that teachers and students in American public schools have to computer technology has grown dramatically in the last two decades. In 1994, only 35% of public schools had access to the Internet (Gray & Lewis, 2009). By 2003, 100% of public schools had Internet access. Between 1995 and 2005, the average number of instructional computers per school more than doubled, from 72 to 154. As the number of computers per school has increased, the ratio of public school students to instructional computers with Internet access has decreased dramatically, from 12.1 in 1998 to 3.8 in 2005 (Gray & Lewis, 2009).

The technological resources that have become available to teachers for instructional purposes in recent years are extensive, as well. As of 2008, 85% of public school districts provided online student assessment tools to at least some of their elementary and secondary school teachers (Gray & Lewis, 2009). Ninety percent of public school districts offered online curricula to some or all of their elementary and secondary school teachers, and over 80% of districts offered server space for elementary and secondary school teachers to create web pages or post class materials.

Despite the widespread access to technology in schools, the evidence linking technology to student achievement is inconclusive. Numerous studies have identified low use of technology across schools (Bain, 2004; Cavanaugh, Dawson, & White, 2007; Cuban, 2001; Cuban, Kirkpatrick, & Peck, 2001; Ross & Strahl, 2005; Shapely et al., 2009; Windschitl & Sahl, 2002; Zhao, Pugh, Sheldon, & Byers, 2002). In classrooms where technology is being employed, it is often used for lower-order tasks such as word processing or searching the Internet (Barron, Kemker, Harmes, & Kalaydjian, 2003; Becker, 2001; Cavanaugh et al., 2007; Cuban et al., 2001; Drayton, Falk, Stroud, Hobbs, & Hammerman, 2010; Vanatta & Fordham, 2004; Zhao & Frank, 2003).

The low use of technology, and the use of technology for lower-order tasks, makes it difficult to draw conclusions about the relationship between technology use and student achievement. One likely reason for the lack of evidence linking technology use to student achievement outcomes in mathematics is that the use of computers is lower in mathematics classes than other content areas (Bebell & Kay, 2010; Corn, Halstead, Tagsold, Townsend, & Patel, 2011; Grimes & Warschauer, 2008; Sclater, Sicoly, Abrami, & Wade, 2006). The infrequent use of technology in mathematics makes it especially difficult to correlate the use of technology in mathematics and students' mathematics achievement. Despite this challenge, some studies have identified a positive relationship between the use of technology in mathematics instruction and mathematics achievement (Campuzano, Dynarski, Agodini, & Rall, 2009; Hunter & Greever-Rice, 2007; Lowther, Ross, & Morrison, 2003; Mollette, Townsend, & Townsend, 2009; Mollette, Overbay, Corn, Townsend, & Townsend, 2010;

Shapley, Sheehan, Maloney, & Caranikas-Walker, 2010). However, other studies have identified either a nonexistent or a negative relationship between technology use and students' mathematics achievement (Bebell & Kay, 2010; Dunleavy & Heinecke, 2008; Dynarski, Agodini, Heaviside, Novak, & Campuzano, 2007; O'Dwyer, Russell, Bebell, & Seeley, 2008; Richtel, 2011; Sclater et al., 2006).

The manner in which technology is used in instruction has been found to be related to student achievement (Becker, 2001; Lei & Zhao, 2007; Warschauer, Knobel, & Stone, 2004; Wenglinsky, 1998). Wenglinsky's (1998) study of the 1996 NAEP dataset, for example, revealed that students whose teachers use technology to teach higher-order thinking skills had higher achievement in mathematics. Students whose teachers used technology to teach lower-order thinking skills were found to have lower achievement in mathematics (Tienken & Maher, 2008; Wenglinsky, 1998). While these findings are not surprising, it is clear that the use of technology alone is not a panacea for improved student achievement.

Teachers tasked with incorporating technology into instruction can benefit from professional development. Access to professional development in technology has the potential to increase teachers' technical knowledge and encourage the use of technology in instruction (Kanaya, Light, & Culp, 2005; King, 2002; Silvernail & Buffington, 2009; Swan & Dixon, 2006; Swan, Kratcoski, Mazzer, & Schenker, 2005). However, many teachers are not provided sufficient professional development in technology to implement innovative, technology-centric lessons in the classroom (Kleiman, 2000; Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009; Zucker & Hug, 2007). Further, teachers' exposure to professional development in technology tends to vary across schools (Wenglinsky, 1998).

Wenglinsky found that teachers of urban and rural students were less likely to have received professional development in technology than teachers of suburban students. The variance in teachers' exposure to professional development in technology makes it challenging to measure the relationship between professional development, technology use in the classroom, and student achievement.

Lastly, although there is extensive research on the gender gap in mathematics (see Friedman, 1989) and the digital divide (Sutton, 1991), there is little research on role gender has played in the relationship between the use of technology in instruction and student achievement in mathematics. One study that looked at the performance of female students in a technology initiative, the evaluation of Enhancing Missouri's Instructional Networked Teaching Strategies (eMINTS), found that female students in eMINTS classrooms outperformed female students in non-eMINTS classrooms in mathematics (Hunter & Greever-Rice, 2007), indicating that female students experienced a greater benefit from exposure to technology in the classroom than male students. However, Attewell and Battle (1999) found that girls with a home computer performed worse on the reading and math tests than boys with a home computer, indicating that the relationship between gender, technology use, and achievement is not without variation.

Purpose of the Study

The purpose of this study is to examine the relationship between the use of computer technology in instruction and student achievement in mathematics across a wide spectrum of students and schools. Of particular interest are the roles that the gender of the student, teachers' exposure to professional development in technology, and specific uses of computer technology play in the relationship between the use of computer technology in mathematics classes and student achievement in mathematics. Three research questions guide the study:

1(a): What is the relationship between the frequency of use of computer technology in mathematics classes and student achievement in mathematics?

1(b): Does the relationship between the frequency of use of computer technology in mathematics classes and student achievement vary by the gender of the student?

2(a): What is the relationship between specific types of use of computer technology in mathematics classrooms and student achievement in mathematics?

2(b): Does the relationship between specific types of use of computer technology in mathematics classrooms and student achievement vary by the gender of the student?

3(a): What is the relationship between mathematics teachers' professional development in technology and student achievement in mathematics?

3(b): Does the relationship between mathematics teachers' professional development in technology and student achievement in mathematics differ by the gender of the student?

Taken together, these questions not only examine the extent to which computer technology is related to math achievement after controlling for potentially confounding variables, but also the extent to which computer technology use in the classroom correlates similarly with achievement for male and female students. To answer these research questions, this study utilized data from the Education Longitudinal Study of 2002 (ELS:2002), collected by the National Center for Education Statistics (NCES). The ELS:2002 is a nationally representative sample of high school students. This study focuses on data collected from students and teachers during the base year (2002), when the students were in their sophomore year of high school.

Significance of the Study

The amount of money being spent on technology in schools seems to be increasing exponentially. In 1996, states spent $81 million on instructional technology (Kleiner, 2003). By 2006, that total had increased to $6.8 billion (Greaves & Hayes, 2006). The amount of money spent implementing computer-based technology in public schools since 1996 has topped ten billion dollars (O'Dwyer et al., 2005). As schools and districts cut funding for teachers, staff, and programs, the money spent on technology does not appear to be dwindling. For example, in the same year that New Jersey cut state support to several school districts, it invested $10 million on classroom computers (Oppenheimer, 1997). A school in Los Angeles cut its entire music program to fund a technology facilitator. Teaching positions in art, music, and physical education were cut in Mansfield, Massachusetts while the district spent $333,000 on computers.

Yet, there is no clear relationship between the use of technology in instruction and student achievement. With the amount of money and time being dedicated to implementing technical initiatives across the country, it is important to identify the relationship between computer use in the classroom and student achievement. Previous research has identified varying student outcomes based on the manner in which computers are being used in the classroom (Lei & Zhao, 2007; Wenglinsky, 1998). Further study of these relationships may contribute to suggestions for best practices for educators using technology in instruction. It may also help to guide our understanding of instructional practices that may be contributing to inequities in mathematics achievement. If the use of technology is, in fact, beneficial to student achievement, identifying the most effective methods of implementation would be efficient both in terms of cost and in terms of professional development and training for teachers.

Further, the interaction between gender and computer technology use in mathematics classrooms has not been fully explored. The achievement of male and female students in mathematics has been rigorously studied (see Friedman, 1989), as has the relationship between gender and technology use (see Sutton, 1991). However, few studies have investigated the role gender may play in the relationship between the use of computers in mathematics instruction and student achievement. Although the gap in access to computer technology has narrowed to the point of being almost equal, the disparity between males and females in terms of technical skill has gotten larger (van Dijk, 2005). More research into the outcomes of female students using technology in mathematics is necessary to identify instructional practices that eliminate, rather than exacerbate, this disparity.

Further, teachers' access to professional development in technology has been found to be related to improvements in teachers' technical knowledge and student achievement (Darling-Hammond, 1999; Kanaya et al., 2005; King, 2002; Silvernail & Buffington, 2009; Swan & Dixon, 2006; Swan et al., 2005; Wenglinsky, 2000). However, few teachers receive professional development in technology that is of sufficient duration and/or quality to engender the kind of pedagogical changes that are associated with improvements in student achievement (Darling-Hammond et al., 2009; Kleiman, 2000; Zucker & Hug, 2007). It is important to investigate the role that professional development in technology plays in both the use of technology in the classroom and in student outcomes to inform effective professional development for teachers.

Limitations of the Study

Although there are several advantages to utilizing a large scale national data set, notably (a) sufficient power to discern statistical significance, (b) generalizability because of the representative nature of those sampled, (c) access to dozens of student- and teacher-reported variables related to computer technology in mathematics classrooms, there are a few limitations to using the ELS:2002. Because the subjects in this study are 10th grade students, the external generalizability of the results is limited. The relationship between the use of technology in the classroom and student achievement has been found to vary by subject and grade level (Antonietti & Giorgetti, 2006; Barron et al., 2001; Bebell & Kay, 2010; Becker, 2001; Cuban et al., 2001; Dunleavy & Heinecke, 2008; Grimes & Warschauer, 2008; Sclater et al., 2006; Wenglinsky, 1998), so the findings of this study may not be applicable to students in other grade levels and other subjects. Additionally, the relationship between professional development in technology and teachers' technology use may vary by discipline and by school level, so it is possible that the findings of this study are only applicable to high school mathematics teachers.

Students who reported that they used computer technology in their mathematics class were asked more comprehensive questions about the manner in which technology was being used. Students were not asked the same questions about the use of technology in their English classes. Focusing on student achievement in mathematics as the outcome variable of interest permits a more in-depth analysis of the relationship between the use of computer technology and student achievement (i.e. Research Question 2). For this reason, the relationship between computer technology use and student achievement in English is not investigated in this study.

The data analyzed in this study reflects the use of computers, and the relationships between such use and student achievement, in 2002. Technology is a rapidly changing tool, and the amount of money and effort invested in technology in education has only increased in the interim. It is possible that, with changes in technology, the advances in technology's applicability to education, and teachers' increasing awareness of the potential applications of technology in instruction, more current data may provide different results.

Lastly, there are a plethora of recent studies on technology use in classrooms. However, these studies are limited in scope: (a) focusing on a small, non-representative sample of students or teachers, (b) emphasizing specific technology (e.g., iPad, SmartBoard, a specific video game), and do not assess technology use and general achievement in math. In brief, the ELS:2002 has the breadth of data to answer these research questions.

Definition of Terms

The term *technology* is somewhat vague. When one thinks of technology, one may think of personal computers and/or handheld devices like iPhones or Blackberries. However, in the context of education, technology is commonly referred to as instructional technology or information and communication technology.

This study seeks to determine the relationship between the use of computers and student achievement in mathematics. All methodology and results focus solely on students' use of computers (desktop or laptop) in the classroom and teachers' exposure to professional development related to the use of computers (desktop or laptop). In these sections, technology is referred to as *computer technology* to clearly indicate what is being discussed. For the sake of situating this study in the large discussion of technology achievement, the review of literature considers technology within the scope of computer-based technology. Therefore, when discussing the relationship between the use of technology in instruction and student achievement, the form of technology being studied is clearly articulated.

This study also seeks to determine the influence that mathematics teachers' professional development in technology has on student achievement in mathematics. An extensive definition of professional development can be found in No Child Left Behind Act of 2001. For the purposes of this paper, the following excerpt of the No Child Left Behind definition will serve as a guide:

> [professional development will] to the extent appropriate, provide training for teachers and principals in the use of technology so that technology and technology applications are effectively used in the classroom to improve teaching and learning in the curricula and core academic subjects in which the teachers teach (Section 9101, 34xi)

Although the term *professional development* is applied to a seemingly boundless range of learning opportunities, this study focuses on mathematics teachers' professional development in computer technology. To provide a framework for this study, the second chapter identifies and discusses teachers' professional development in a variety of technical initiatives. However, for the last three chapters of this study, the term *professional development* will refer to mathematics teachers' self-reported exposure to training related to the use of computers, as operationalized by ELS:2002.

Equity and equality are terms that are often used interchangeably. Both terms describe parity among different groups. In the context of this study, the term equality describes the quantity of exposure to computers in the classroom, while the term *equity* describes the use of computers in the classroom with regard for the implications of that use. For this reason, the term *equity*, as it relates not only to the use of computers in the classroom but also to the relationship between the use of computers and achievement, will be used to describe differences between male and female students.

Overview of Approach

This quasi-experimental quantitative study seeks to determine the relationship between computer technology use in the classroom and student achievement in mathematics outside of a specific technological intervention. The structure of the study primarily builds on Wenglinsky's (1998) study, which investigated the relationship between the use of educational technology and academic achievement, as measured by the 1996 NAEP, and the social environment of the school. This study, however, is different than Wenglinsky's in important ways: (a) the data in this study reflects the manner in which computer technology is used in the classroom as reported by 10^{th} grade students, (b) this study focuses on the gender equity of computer technology use in mathematics, and (c) this study relies solely on student-reported data concerning instructional practices using computers and teacher-reported data concerning exposure to professional development. In contrast, Wenglinsky focused on teacher reported data and does not address gender equality.

This study utilizes data from the ELS:2002, a nationally representative sample of high school students. This study focuses on data collected during the base year (2002), when students were in their sophomore year of high school. A total of 15,362 students and 7,135 teachers completed the base year questionnaire. The dependent variable for this study is students' standardized score on the mathematics test administered for the ELS:2002. Independent variables were selected to address the research questions and to control for the influence of potentially confounding predictors. These variables include a measure of the frequency with which computers are used in students' mathematics class, the frequency with which computers are employed for specific purposes in students' mathematics class, students' mathematics teachers' exposure to professional development in technology, and students' gender. Control variables include a measure of students' socioeconomic status, students' race, students' use of a home computer, mathematics teachers' age and years of experience, the type of school (public or private), and the urbanicity and poverty of the students' school. Multilevel modeling (MLM), also known as hierarchical linear modeling (HLM), will be used to address each of the three research questions. MLM was selected as the primary method of analysis because it accounts for the nested nature of the dataset (students within schools), allows for estimates of between-school and within-school variability, and can manage unbalanced data

Chapter Summary

This chapter provided an introduction to the study, including an overview of the study's purpose and research questions, the significance of the study, the limitations of the study, a definition of key terms, and a brief description of the approach. The next chapter describes the literature on the use of technology in instruction and its relationship to student achievement. The summary of existing theoretical and empirical literature provides a framework for the study. Chapter 3 describes the data, the variables selected for the study, and the methodology followed to address the three research questions. Results of the analysis are presented in Chapter 4, and a discussion of the results in terms of theoretical and empirical implications and suggestions for future research is presented in Chapter 5.

CHAPTER 2

Review of Literature

Introduction

It is clear that technology holds great promise to many in education. It is regarded as a tool that can work wonders: improve student achievement, increase student engagement, and close the digital divide (Edwards, 2003; Gray et al., 2001; Stallard & Cocker, 2001; Swain & Pearson, 2003). Research has shown that when students receive individualized instruction, their scores on standardized tests are an average two standard deviations above the scores of students taught with conventional methods of instruction (Bloom, 1984). A report issued by the President's Information Technology Advisory Committee (2001) stated that instructional technology "has the benefits of one-on-one tutoring and group interactions" (p. 6). The use of technology in instruction may allow educators to provide individualized instruction to every student.

Further, as stated by Kolderie and McDonald (2009), "using IT to personalize learning enables and empowers young people to pursue their own knowledge . . . By redesigning schools to incorporate new technologies, we can dramatically increase the personalization of American education with little marginal increase in labor costs" (p. 7). However, technology is an expensive tool, and it is important to know whether it is meeting these great expectations. Is technology a tool that educators can use to better serve students, or is it just the latest in a long history of reforms?

An investigation of existing research on the use of technology in instruction provides a framework on which to build. Fink (2010) defined a research literature review as "a systematic, explicit, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners" (p. 3). This literature review explores the relationship between the use of technology, both in the classroom and at home, and student achievement. The first section of this literature review contains an overview of the use of technology in K-12 instruction. This overview lends context to the current study. The second section explores the relationship between students' use of technology and student achievement. A summary of studies investigating student outcomes in technology interventions is presented. The third section presents a summary of studies investigating the relationship between the use of a computer at home and student achievement. The fourth section of this literature review explores the relationship between the use of technology in instruction and measures of the social environment of the school. The final section discusses the role of professional development on teachers' use of technology in instruction.

Use of Technology in Instruction

Despite widespread access to computers and other forms of instructional technology in schools, the use of technology in instruction remains low (Bain, 2004; Cavanaugh et al., 2007; Cuban, 2001; Cuban et al., 2001; Ross & Strahl, 2005; Shapely et al., 2010; Windschitl & Sahl, 2002; Zhao, Pugh, Sheldon, & Byers, 2002). When teachers do incorporate technology into instruction, they primarily use it for lower-order tasks such as word processing and searching the Internet (Barron et al., 2003; Becker, 2001; Cavanaugh et al., 2007; Cuban et al., 2001; Drayton et al., 2010; Vanatta & Fordham, 2004). In many cases, technology is used primarily in manners that support teachers' existing patterns of instruction, such as for taking notes (Cuban et al., 2001; Suhr et al., 2010; Windschitl & Sahl, 2002). The lack of innovative lessons incorporating technology into instruction lends credence to those who suggest that technology is just the latest in a long line of unsuccessful education reforms (Bianchi, 2004; Cuban, 2001; Cuban, 2006; Vascellaro, 2006). As Clifford Stoll stated in a 1996 article in *The New York Times*, “Computers in classrooms are the filmstrips of the 1990s. We loved them because we didn’t have to think for an hour, teachers loved them because they didn’t have to teach, and parents loved them because it showed their schools were high-tech. But no learning happened.” (p. B4)

Cuban et al.’s (2001) study of the use of technology in two high schools in Silicon Valley revealed little use of technology across subjects and grade levels. When shadowing students at the two schools, the researchers observed that only nine of 35 teachers incorporated the use of technology into instruction. Although the researchers identified a few teachers who had embraced technology and developed lessons to incorporate them into instruction, most teachers chose not to use technology, or to use it only when technology fit into their standard teaching practice. Ross and Strahl (2005) identified similar patterns of use in their evaluation of the first year of the Freedom to Learn program, which provided laptop computers to middle school students, in Michigan. Observations of participating classrooms revealed that approximately two-thirds of students were not using computers as a tool for learning. Only about 17% of observed classes utilized technology for instructional delivery.

Windschitl and Sahl (2002) investigated the way three teachers at a Catholic middle school adapted to a ubiquitous computing environment. The teachers were shadowed throughout the school day for three weeks during the middle of the school year. Of the three teachers shadowed, only one, who taught both language arts and social studies, regularly incorporated technology in lessons. The mathematics teacher made initial attempts at integrating technology into instruction, but by the end of the second year, his use of technology in the classroom had dwindled to the use of websites for enrichment work for certain students. The other teacher, a language arts and social studies teacher who exhibited the most reluctance to incorporate technology into instruction, stated that she felt that laptops interrupted the flow of the day, they were a distraction to learning, and there was not adequate time to develop ways to incorporate technology into her lesson plans.

Barriers to Implementation

The apparent lack of higher-order uses of technology in instruction merits further discussion. Of interest are the barriers that teachers face when tasked with adopting new technology in the classroom. One of the most commonly reported barriers to the implementation of technology in instruction is the lack of sufficient time to learn to use the technology and to develop lesson plans incorporating technology (Cuban et al., 2001; Shapely et al., 2010; Silvernail & Harris, 2003; Soorma, 2008). Evaluations of the use of technology in instruction have repeatedly revealed concerns among teachers about the amount of time required to become proficient with the use of the new technology. For instance, Silvernail and Harris's (2003) evaluation of the Maine Learning Technology Initiative found that teachers routinely reported not having enough time to both learn to use the laptops and to develop ways to incorporate the laptops into instruction. Sclater et al.'s (2006) mixed methods study of the one-to-one project in Quebec found that secondary teachers participating in the one-to-one project were more likely to report that technology:

"a) requires extra time to plan learning activities; b) is too costly in terms of resources, time and effort; and c) requires software-skills training that is too time consuming" than control group teachers.

Whereas time is commonly viewed as a barrier to instructional technology use, professional development has been linked to increased use of technology (Silvernail & Harris, 2003; Shapely et al., 2010; Vanatta & Fordham, 2004). Technological Pedagogical Content Knowledge (TPCK, also referred to as TPACK) serves as a framework for what teachers should know when tasked with incorporating technology into instruction (Mishra & Koehler, 2006). It is based on the integration of technology, pedagogy, and content knowledge. The framework suggests that when technological, pedagogical, and content knowledge are present, teachers are prepared to effectively incorporate technology into their instruction. The framework builds on the pedagogical content knowledge (PCK) framework posited by Shulman (1986). It is possible that providing teachers with a greater understanding of effective methods of implementing technology in instruction would encourage teachers to utilize technological tools more frequently. The primary manner of infusing in-service teachers with such knowledge is through professional development. The evaluation of the Maine Learning Technology Initiative found that teachers who participated in professional development related to technology tended to report higher rates of technology use in the classroom than teachers who did not participate in professional development (Silvernail & Harris, 2003). Vanatta and Fordham's (2004) survey of teachers at six schools in Ohio revealed that the amount of technology training that teachers received was a predictor of technology use in the classroom. However, few teachers receive professional development in technology that are of sufficient duration and/or quality to stimulate pedagogical change (Darling-Hammond et al., 2009; Kleiman, 2000; Zucker & Hug, 2007).

Technical problems and unreliable technology are also reported as barriers to full implementation in the classroom (Corn et al., 2011; Cuban et al., 2001; Silvernail & Harris, 2003; Windschitl & Sahl, 2002). In Cuban and colleagues' (2001) study of the use of technology in two high schools in California, teachers reported that technical problems, such as crashing servers and inadequate wiring, that hindered the use of technology. Some teachers also reported that they prepared back-up lessons for the occasion when the technology was not fully operational. Similarly, Windschitl and Sahl (2002) identified a lack of adequate technical support as a barrier to use, and an avid technology user in their study reported that wireless modems used at the school were at times too slow to access the Internet. Teachers are understandably hesitant to base instruction on technology that is unreliable.

Implementation Across Grade Levels and Subject Areas

Demographic characteristics of the teacher, such as gender and and teachers' experience with technology have not been found to be predictors of technology use in the classroom (Antonietti & Giorgetti, 2006; Cuban et al., 2001). However, an inverse relationship between teachers' years of experience and teachers' confidence with technology has been identified (Mollette et al., 2010; Russell et al., 2003). Years of experience could serve as a proxy for age, and it is likely that younger teachers have had greater exposure to technology in their education and at home than older teachers. Grade levels and content areas are also predictors of technology use (Antonietti & Giorgetti, 2006; Barron et al., 2001;

Bebell & Kay, 2010; Becker, 2001; Corn et al., 2011; Cuban et al., 2001; Grimes & Warschauer, 2008; Sclater et al., 2006). In particular, elementary school teachers tend to be more willing to integrate technology into the curriculum than their high school counterparts. For instance, elementary school teachers in a large school district in Florida were far more likely to use computers as a problem-solving or decision-making tool than high school teachers (Barron et al., 2001). Elementary school teachers were also far more likely to use computers for communication than high school teachers.

Secondary school teachers rated the role of thinking processes in the use of multimedia lower than kindergarten and primary school teachers, indicating a lack of "buy-in" to the value of technology as an instructional tool (Antonietti & Giorgetti, 2006). Moreover, kindergarten teachers were more likely to believe computers played a role in students' ability to develop visual and global understanding than primary and secondary teachers. Antonietti and Giorgetti's (2006) survey also identified differences in how teachers of science and humanities viewed the use of computers in instruction. The findings showed that science teachers were less likely to believe computers improved logical reasoning, assigning this factor a lower score than humanities teachers.

Teachers of certain content areas find that technology naturally complements their existing pedagogy. Technology, specifically computers, lends itself particularly well to English/Language Arts (ELA) instruction. Word processing software enables students to efficiently write and edit essays and reports. In addition, students can use computers to conduct research on the Internet and create presentations using Microsoft PowerPoint©. Possibly for this reason, the use of technology tends to be more frequent in ELA classrooms than in other core content areas (Barron et al., 2003; Bebell & Kay, 2010; Becker, 2001; Corn et al., 2011; Cuban et al., 2001; Grimes & Warschauer, 2008; Sclater et al., 2006).

Other qualities that explain the use of technology in instruction generally fall into four categories identified by Bain (2004):

1. Separate courses in computer education,
2. Pre-occupational preparation in business and vocational education,
3. Various exploratory uses in elementary classes, and
4. The use of word processing software for students to present work to their teachers.

As discussed earlier, the common use of word processing software, particularly in ELA classes, reflects Bain's fourth category of use. Analysis of the Teaching, Learning, and Computing (TLC) survey supports Bain's first three categories of use (Becker, 2001). The survey, which was administered to more than 4,000 teachers in 1998, found that students were most likely to be exposed to technology in self-contained classes in elementary school and in technology/vocational classes in high school.

Uninspired Implementation

Studies that have focused on the manner in which technology is being used in the classroom repeatedly identify "uninspired" (Cuban et al., 2001) implementation (Barron et al., 2003; Becker, 2001; Cavanaugh et al., 2007; Cuban et al., 2001; Drayton et al., 2010; Vanatta & Fordham, 2004; Zhao & Frank, 2003; Zucker & Hug, 2007). Time and time again, research on the use of technology in education reveals that computers in the classroom are primarily being used for drill and practice exercises, word processing, and searching the Internet. For example, Cuban et al.'s (2001) study of the use of computer technology in two high schools in Silicon Valley indicated that computers were rarely used across all subjects and grade levels. When students were using computers, they were most often using them to type assignments, work on reports, and search the Internet (Cuban et al., 2001).

Other studies have identified the use of computers for communication, or email, as another common application. A survey administered to teachers to investigate the relationship between teachers' attitudes towards technology and technology use revealed that the most common applications of technology were for word processing, email, and the Internet (Vanatta & Fordham, 2004). Barron et al. (2003) also found that teachers used computers most often for communication.

Drayton et al.'s (2010) study of three schools that had been implementing ubiquitous computing for at least five years revealed similar patterns of technology use at each school. The study focused on one urban public school, one rural public school, and one private school with about 80% of its population comprised of boarding students. At the rural public school, teachers reported that students used technology to access their teacher's website and the Internet. At the urban public school, students used Microsoft Word©, the Internet, the school Intranet, and email most frequently. At the private school, the most frequently used applications were email, Microsoft Word©, and the school Intranet. Across all three schools, computers were used most often as tools for communicating, whether via the school Intranet or the Internet, email, or word processing software.

Implementation Across Student Subpopulations

The discussion thus far has identified the lack of inspired implementation of technology in the classroom. However, both the frequency and the manner in which technology is used in the classroom tend to vary across subgroups of students. In particular, students of low socioeconomic status have been exposed to more frequent but lower-order uses of technology than students of high socioeconomic status (Becker, 2001; Warschauer et al., 2004; Wenglinsky, 1998). Becker's (2001) analysis of the Teaching, Learning, and Computing (TLC) survey found that mathematics, social studies, and English teachers at schools with a large population of low-socioeconomic students were more likely to use computers frequently in the classroom than teachers at schools with a small population of low-socioeconomic students. The opposite was true for science teachers: Science teachers at more affluent schools were more likely to use computers frequently in the classroom than science teachers at less affluent schools.

In a study of five schools with large low-socioeconomic status populations and three schools with small low-socioeconomic status populations in California, Warschauer et al. (2004) found a fairly even distribution of computers across both categories of schools. However, the manner in which those computers were used in instruction differed according to the socioeconomic status of the student body of the school. For example, in mathematics classes, students at less affluent schools used computers for visualization software and individualized instruction, while students at more affluent schools used computers for statistical analysis. In ELA classes, students at less affluent schools used computers primarily to write essays and create Microsoft PowerPoint© presentations. At schools with small low-socioeconomic status populations, students primarily used computers to conduct research on the Internet, create Microsoft PowerPoint© presentations, and plan, write, edit, and analyze essays.

Further, Wenglinsky (1998) found that students of low socioeconomic status were less likely to be exposed to higher order uses of technology than students of high socioeconomic status. Weaver (2000) also identified a disparity in the use of technology across socioeconomic status. Her analysis of the NELS:88 dataset revealed that students of high socioeconomic status reported greater frequencies of computer use at school than students of low socioeconomic status. Wenglinsky's (1998) study of the NAEP dataset also revealed that students of different races were being exposed to different uses of technology, as were students at urban and rural schools. Urban and rural students were less likely to be exposed to higher-order uses of technology than suburban students. Black students in the fourth grade were more likely to use a computer at school than White students in the fourth grade. In eighth grade, Black students were less likely to be exposed to higher-order uses of technology than White students.

Becker's (2001) study identified variance in the use of computers by ability. The use of computers in mathematics was related to the ability of the students in the class. Students in low ability mathematics classes at low-socioeconomic schools were more likely to use computers frequently in the classroom than students in high ability mathematics classes. However, students in high ability mathematics classes were more likely to use spreadsheets and exploratory math software than students in low ability mathematics classes. Across all subjects, computers were used to play games more often in low ability classes than in high ability classes.

The reason behind some of these disparities in use may be explained by the different learning environments in high and low socioeconomic status schools. Interviews with teachers at low socioeconomic status schools in Warschauer et al.'s (2004) study indicated that teachers felt hesitant to create innovative lessons using technology because of the pressure to prepare students for high-stakes tests. Teachers expressed a concern that the use of technology would take time away from covering the basic skills that they felt students needed to pass the tests. Teachers also reported that they avoided assigning work that required students to use computers outside of the school day because of a concern that students did not have a computer at home.

Technology and Mathematics Achievement

The research on the relationship between the use of technology in instruction and student achievement tends to focus on the two most highly tested subjects: mathematics and reading/writing. Because this study focuses on the factors influencing computer technology use in mathematics, this section will focus on studies of instructional technology that analyzed student achievement in mathematics. The following section will focus on how different uses of technology in the classroom relates to student achievement.

The use of computer technology in mathematics instruction is often infrequent or nonexistent, making it difficult to conduct research on the relationship between use and achievement (Barron et al., 2003; Bebell & Kay, 2010; Becker, 2001; Corn et al., 2011; Cuban et al., 2001; Grimes & Warschauer, 2008; Lemke & Martin, 2004; Sclater et al., 2006). Despite this challenge, several recent studies have identified a positive relationship between the use of technology in instruction and mathematics achievement (Campuzano et al., 2009; Hunter & Greever-Rice, 2007; Koedinger, McLaughlin, & Heffernan, 2010; Lowther et al., 2003; Mollette et al., 2010; Shapely et al., 2009; Shapely et al., 2010). For example, Lowther et al.'s (2003) study of a one-to-one initiative at 61 schools in Florida revealed a positive and relationship between participation in the project and mathematics achievement among sixth and seventh grade project groups.

The evaluation of the Technology Immersion Pilot (TIP) in Texas yielded a positive effect in math (Shapely et al., 2009). The TIP provided each student and teacher with a laptop at 21 middle schools across the state of Texas. Twenty one schools were selected to serve as control schools. Analysis of students' Texas Assessment of Knowledge and Skills (TAKS) scores revealed that seventh and eighth grade students at TIP schools significantly outperformed students at control schools in math, although there was no difference in ninth grade students' scores.

The evaluation of the Enhancing Missouri's Instructional Networked Teaching Strategies (eMINTS) project also revealed a positive relationship between participation in eMINTS and student achievement (Hunter & Greever-Rice, 2007). Teachers in the program received a classroom computer and individual laptop, and each classroom was equipped with a scanner, printer, digital camera, SMART© Board, and a computer for every two students. Analysis of the Missouri Assessment Program (MAP) mathematics test revealed that students in eMINTS classrooms outperformed students in non-eMINTS classrooms. Among subgroups, there were no differences among Individualized Education Program (IEP) students, Title I students, Black students, and White students. Subgroups of students in eMINTS classrooms who outperformed non-eMINTS students in mathematics included students qualifying for free or reduced-price lunch (FRL), non-Black non-White students, female students, and male students. Non-Black, non-White eMINTS students demonstrated the greatest benefit to their mathematics achievement, with an average score 19 points higher than non-Black non-White non-eMINTS students.

Koedinger et al.'s (2010) study of a formative assessment software program identified a positive relationship between the use of the software and student achievement in mathematics. The focus of the study was the use of ASSISTment, a software program designed to give students hints and feedback on their answer choices while it collects assessment data. The investigation of middle school students' use of ASSISTment found that students that had used ASSISTment significantly outperformed students that had not used ASSISTment on the Massachusetts Comprehensive Assessment System (MCAS) after controlling for pretest scores. Special education students demonstrated the greatest gain related to use of ASSISTment. However, students using ASSISTment who were labeled as "advantaged" (regular education, white, male, not free or reduced-price lunch eligible, and not of Limited English Proficiency) did not outperform their control group counterparts.

Another study of the ASSISTment software found that fifth grade students demonstrated significantly more learning when using the software to complete homework rather than doing homework with paper and pencil (Mendicino, Razzaq, & Heffernan, 2009). Students were assigned problems to complete using the software at home; however, several students did not have Internet access at home. Of the 92 students in the study, only 28 completed the software homework at home. It is possible that those students with access to both a computer and the Internet at home are students of greater socio-economic status, which may have influenced students' learning outcomes.

Other studies suggest that the use of technology has no effect, or a variable effect, on student achievement in mathematics, depending on the manner in which technology is used (Bebell & Kay, 2010; Cuban et al., 2001; Dynarski et al., 2007; Isiksal & Aksar, 2005; Lei & Zhao, 2007; Pierce, 2007; Richtel, 2011; Tienken & Maher, 2007). For instance, Bebell and Kay's (2010) study of data from the third year of implementation of the Berkshire Wireless Learning Initiative (BWLI), a one-to-one project that was implemented in five middle schools in Massachusetts beginning in 2005, found that students participating in the BWLI project who reported using technology more often tended to score higher on the mathematics assessments than BWLI students who reported using technology less often. However, comparison students who reported using technology more often tended to score lower on the mathematics assessments than comparison students who reported using technology less often. Among BWLI students, there was a positive relationship between the use of technology in mathematics classes and achievement on mathematics tests, although the relationship between the use of technology in all core subjects and student achievement was negative for comparison students. These findings suggest that the manner in which technology was being used at project and control schools may have had an effect on student achievement outcomes.

In a study of student outcomes after the second year of implementation of a one-to-one project in North Carolina, Corn (2009) found that students participating in the one-to-one project were less likely to pass the Algebra I, Algebra II, and Geometry End-of-Course (EOC) exams than students at non-one-to-one schools, although there was some evidence that pass rates of students at one-to-one project schools were beginning to improve. However, it is difficult to assess the effectiveness of the one-to-one project based on these achievement trends, as the pass rates at the one-to-one schools were generally lower than or comparable to those at comparison schools prior to involvement in the project.

Richtel's (2011) report on the standardized test scores of students in the Kyrene School District in Arizona detailed the lack of improvement in student achievement despite the $33 million investment in technology. Since approving a measure to introduce computers and other instructional technology in 2005, mathematics scores in the district remained flat while statewide average scores increased.

Sclater et al.'s (2006) study of the one-to-one project in Quebec initially found no relationship between participation in a one-to-one project and mathematics achievement. However, after matching project and control group students based on pre-test scores, students in the project group scored lower on the mathematics assessment than comparable students in the control group, indicating that participation in the one-to-one project was negatively related to achievement. Similarly, O'Dwyer and colleagues' (2008) study of data from the Use, Support, and Effect of Instructional Technology (USEIT) Study found that the frequency with which students used computers in school was negatively related to student achievement in geometry.

Disparities in Use of Computers

This literature review has thus far described research that suggests a positive relationship, a negative relationship, and a variable relationship between the use of technology in instruction and student achievement in mathematics. The logical question to ask at this point is, "Why is the relationship between technology use in the classroom and student achievement so variable?" Some research suggests that the manner in which technology is used in instruction varies across subgroups of students. This inconsistency in implementation may be a factor in the variance in achievement outcomes.

Bebell and Kay (2010), for example, suggested that the manner in which technology is used is relevant to its relationship to student achievement. They found that students' use of technology for communication was positively related to mathematics achievement. However, student use of technology to present information in class was negatively related to mathematics achievement. Tienken and Maher's (2008) study of eighth grade students at a middle school in New Jersey indicated that the presence of Computer Assisted Instruction (CAI) was negatively related to student achievement for the lowest achieving students. Students in the study primarily used the CAI for drill and practice in their mathematics classes. The researchers found that students in the study group who scored in the lowest quartile on the TerraNova mathematics test in 7th grade (which served as a pre-test) scored lower on the New Jersey mathematics proficiency test than students in the control group. In short, the lower-order use of computers in mathematics appeared to be detrimental to the achievement of the lowest-performing students.

The use of technology in the classroom has been shown to be related to different outcomes across subgroups of students. Pierce's (2007) study of the impact of Technology Connections, a project designed to integrate technology into the curriculum, classrooms in Wake County, North Carolina found no differences in overall student achievement. However, she identified different outcomes when disaggregating the data. Technology Connections schools had additional classroom computers and laptops for staff. Of all of the subgroups analyzed, only Asian students in Technology Connections schools received higher scores on the math test than Asian students in comparison schools. Further, participation in Technology Connections appeared to be negatively related to Black students' computer skills. Black students in Technology Connections schools had lower scores on the multiple choice section of the computer skills test than Black students in comparison schools. In addition, both Black students and students of low socioeconomic status had lower scores on the performance section of the computer skills test.

It is likely that such disparities across subgroups are related to the manner in which technology was implemented in the classroom. Black students and students at urban schools, in particular, have been at a disadvantage when it comes to the use of technology (Hess & Leal, 2001; Wenglinsky, 1998). Hess and Leal (2001) identified a disparity in urban students' access to computers. After controlling for family income and state and local per-pupil spending, urban districts with a higher percentage of Black students had a higher student-to-computer ratio than urban districts with a lower percentage of Black students. However, Wenglinsky's (1998) study of the 1996 NAEP data, which did not focus solely on urban districts, identified relatively equal access but different manners in which technology was being used across subgroups. Among 8^{th} grade students, Black students were more likely to be exposed to lower order uses of technology (i.e. drill and practice) than White students.

Technology Use, Math Achievement, and Gender

The previous section described the variation in the manner with which students are exposed to technology in the classroom and the varying achievement effects of technology exposure on different subgroups of students. Of particular interest for this study is the role that gender plays in the relationship between technology use in the classroom and student achievement in mathematics. Although there is extensive research on the gender gap in mathematics (see Friedman, 1989) and the digital divide (see Sutton, 1991), there is little research focused on the role gender plays on student achievement when computer technology is implemented in mathematics instruction. Rather, much of the research on the topic focuses on students' attitudes toward and confidence with the use of computer technology in mathematics. Pierce, Stacey, and Barkatsas (2007), for example, found that male students reported higher ratings of their confidence with technology than female students. Interestingly, the measure of students' attitude towards the use of technology for learning mathematics was positively related to male students' confidence with technology and negatively related to female students' confidence with mathematics. Similarly, Vekiri and Chronaki (2008) found that male students expressed greater computer self-efficacy than female students.

In their investigation of the relationship between the use of technology and mathematics achievement among 7^{th} grade students in Turkey, Isiksal and Askar (2005) did not identify any gender differences with respect to mathematics achievement or self-efficacy in mathematics. However, they found that female students had lower computer self-efficacy than male students, and they identified a positive relationship between computer self-efficacy and mathematics achievement.

Male and female students' different feelings about technology and their skill with technology may affect the manner in which they interact with a technology-centric lesson. A study of students using technology in mathematics in Australia found that 43% of mathematics teachers observed differences in the way male and female students used computers in the classroom (Forgasz, 2006). Teachers reported that male students were more likely to "take risks" and that female students needed more encouragement and assistance when using computer technology. For this reason, Forgasz hypothesized that male students would derive a greater benefit from the use of technology in the classroom than female students.

However, some research suggests that female students benefit more than male students from the use of technology in mathematics. One of the few studies that focused on the role of gender in a technology initiative, the eMINTS evaluation in Missouri, found that female students in eMINTS classrooms outperformed female students in non-eMINTS classrooms on the state mathematics test (Hunter & Greever-Rice, 2007).

Although male and female students generally have equal access to computer technology at school, males outperform females in terms of technical skill (van Dijk, 2005). This disparity in skill may be due in part to students' exposure to computer technology at home. Male students report greater home use of computers than female students (Attewell & Battle, 1999; Ching, Basham, & Jang, 2005; Kim & Bagaka, 2005; Vekiri & Chronaki, 2008). This trend may put female students at a disadvantage, as the use of a computer at home has been found to be positively related to student achievement (Attewell & Battle, 1999; Bebell & Kay, 2010; Fairlie, 2005; Shapley et al., 2010; Wenglinsky, 1998). The disparity in technical skill may influence female students' behaviors and choices into their adult life, as well. Ching et al.'s (2005) study of 130 college students found that female students reported using technology less often than male students. The relationship between students' use of computers at home and student achievement will be discussed in more detail in the next section.

Home Computer Use

As mentioned earlier, students' use of a computer at home has been found to be, for the most part, positively related to student achievement (Attewell & Battle, 1999; Bebell & Kay, 2010; Fairlie, 2005; Shapley et al., 2010; Wenglinsky, 1998). Wenglinsky (1998) found that students' use of a home computer was positively related to their academic achievement, and Shapley et al.'s (2010) more recent study of the Technology Immersion model in 21 schools in Texas also found that student use of technology at home was positively related to student achievement. There is also evidence to suggest that home computer use is positively related to school persistence among high school students (Fairlie, 2005). Fairlie's study of data from the Computer and Internet Usage supplement to the September 2001 Current Population Survey found a relationship between home computer ownership and school enrollment. Focusing on respondents between the ages of 16 and 18 who had not yet graduated from high school, Fairlie found that a greater percentage of children with home computers were still enrolled in school. After controlling for socioeconomic indicators, the percentage of children with home computers who were enrolled in school was slightly greater than the percentage of children without home computers, indicating a possible relationship between the use of a home computer and graduation rates.

The positive relationship between students' use of a home computer and achievement is not necessarily due to the use of the home computer for schoolwork. Students use home computers most often for recreational purposes. Fairlie (2005) found that the four most frequent uses of computers at home were for accessing the Internet, playing games, sending and receiving email, and using a word processor. Bebell and Kay's (2010) study of data from the third year of implementation of the BWLI found the frequency with which students used computers at home for recreational purposes was positively related to English and mathematics achievement. However, O'Dwyer et al.'s (2008) study of data from the Use, Support, and Effect of Instructional Technology Study found that students' use of technology for recreational purposes at home was negatively related to achievement on number sense and operations and achievement on data analysis, statistics, and probability.

There is also evidence to suggest that students who have computers at home adapt more easily to technology-rich environments (Ching, Basham, & Jang, 2005; Cuban, 2001). Cuban's (2001) observations of the use of computers in kindergarten and preschool classrooms in California found that students who had computers at home had an easier time navigating software in the classroom. Ching et al.'s (2005) study of 130 college students suggests that students who had a computer in their home at a younger age tended to use technology at a higher frequency in college than students who did not have a computer in the home at a young age.

Research has documented variations in the relationship between home computer use and student achievement among subgroups. Attewell and Battle's (1999) analysis of the NELS:88 dataset found that girls with a home computer performed worse on the reading and math tests than boys with a home computer. They also found that the effect of home computers was smaller for Black and Hispanic students than it was for White students.

Analysis of the role of socioeconomic status indicated a positive interaction between socioeconomic status and home computer use. This finding indicates that students of higher socioeconomic status with a home computer had higher scores on reading and math tests than students of lower economic status with a home computer.

It is possible that students' use of computers at home can inform the effective use of technology in the classroom. Mumtaz (2001) found that students regularly used computers more frequently at home than at school. The students in her study, conducted at three primary schools in the United Kingdom, reported that they spent more time playing games on their computer than any other activity. Students' different perceptions of the use of the computer at home and at school were striking. While 85% of students reported that they enjoyed playing games on their home computer, 92% reported feeling bored when using the computer at school for typing notes (Mumtaz, 2001). Bebell (2005) also documented students' propensity to use a home computer to play games. These findings shed light on possible strategies to engage students in the classroom through the use of computers. The use of games to promote learning in the classroom, particularly among primary school students, could be beneficial. Wenglinsky (1998), for example, found that the use of educational games among fourth grade students was positively related to student achievement. A study of the use of video games in four high school science classes found that, although no differences in student learning were identified, students' level of engagement was significantly higher in the project classrooms than the control classrooms (Annetta, Minogue, Holmes, & Cheng, 2009).

Technology Use and Social Environment

Some advocates of technology in education point to measures of the social environment, rather than achievement, as an indicator of effectiveness. It is true that studies of technology initiatives tend to report increased student engagement (Bebell & Kay, 2010; Cavanaugh et al., 2007; Grimes & Warschauer, 2008). Observations of classrooms participating in the Leveraging Laptops program in Florida indicated an increase in student engagement, project-based learning, independent inquiry/research, and the use of technology as a learning tool or resource (Cavanaugh et al., 2007). Over half of the teachers in the study reported "an increase in conditions that support learning: enjoyment, motivation, engagement, on-task behavior, and positive school experience." (p. 40). Similarly, Bebell's (2005) study of data from the first year of implementation of the BWLI found a positive relationship between computer use and student engagement. Most teachers (84%) reported that student participation had improved over the course of the project, and 87% observed improved student interaction after the first year of implementation. After the fourth year of implementation, most teachers (83%) reported that student engagement had improved over the course of the project (Bebell & Kay, 2010). Grimes and Warschauer's (2008) study of one-to-one projects in three schools in California found that a majority of teachers (84%) reported that the laptop project increased student interest in class.

In addition to investigating student achievement, Wenglinsky (1998) investigated the relationship between technology use, teacher's professional development in technology, and the social environment of the school as measured by student tardiness and absenteeism, teacher absenteeism, teacher morale, and student regard for school property. He found that teachers' exposure to professional development in technology was positively related to the social environment of the school. Further, the use of technology to teacher higher-order thinking skills was positively related to the social environment.

However, these measures of the social environment can be subjective and may be reflective of factors other than the presence of technology in the classroom. For instance, students may be temporarily awed by the nuance of technology, or engagement may be higher due to a more participatory and/or hands-on method of instruction. In addition, most measures of the social environment are based on a single self-report measure from teachers.

And the relationship between the use of technology at school and the social environment of the school is not always positive. Wenglinsky (1998) found that, among fourth grade students, the use of computers at school was negatively related to the social environment of the school. The use of technology to teacher lower-order thinking skills was also negatively related to the social environment of the school among both fourth and eighth grade students. His findings were corroborated by Waxman, Lin, and Michko's (2003) meta-analysis of 42 studies related to the relationship between instructional technology and student outcomes, which found a small but negative effect of technology use on student behavioral outcomes. Such findings may suggest that the presence of technology in the classroom can at times serve as a distraction to learning. For example, Jaillet's (2004) study of a portable computing initiative in France found that computers were being used to search the Internet, but not for instructional purposes. A survey of students participating in the initiative and those in a control group indicated that students in the initiative visited websites unrelated to instruction far more often than students in the control group. Students in the initiative were also more likely to search for videos and audio tracks unrelated to instruction than students in the control group.

Professional Development

As discussed earlier in this chapter, one of the barriers that teachers face when tasked with implementing technology in the classroom is the lack of adequate professional development. The TPACK framework serves as a guide to what teachers should know when tasked with incorporating technology into instruction (Mishra & Koehler, 2006). Evidence suggests that teachers continue to use technology infrequently (Bain, 2004; Cavanaugh et al., 2007; Cuban, 2001; Cuban et al., 2001; Ross & Strahl, 2005; Shapely et al, 2010; Windschitl & Sahl, 2002). When technology is being used in instruction, it is frequently used for uninspired purposes (Barron et al., 2003; Becker, 2001; Cavanaugh et al., 2007; Cuban et al., 2001; Drayton et al., 2010; Vanatta & Fordham, 2004; Zucker & Hug, 2007). If the pedagogical and content knowledge pieces are in place, then the missing piece of the puzzle, according to the TPACK model, is technological knowledge. It is possible that providing teachers with a greater understanding of effective methods of implementing technology in instruction would encourage teachers to utilize technological tools more frequently and in a more innovative manner. The primary manner of infusing in-service teachers with such knowledge is through professional development. Few teachers receive professional development opportunities in technology that are of sufficient duration and/or quality to stimulate pedagogical change (Darling-Hammond et al., 2009; Kleiman, 2000; Zucker & Hug, 2007). Developing an understanding of what makes professional development beneficial to teachers and students can inform future practice.

Access to effective professional development in technology has been shown to increase teachers' technical knowledge, encourage the use of technology in instruction, and improve student achievement (Darling-Hammond, 1999; Kanaya et al., 2005; King, 2002; Silvernail & Buffington, 2009; Swan & Dixon, 2006; Swan et al., 2005; Wenglinsky, 2000). But what exactly is "effective" professional development? According to research, three primary components of effective professional development are: duration, collaboration, and relevance (Darling-Hammond et al., 2009; Duran, Brunvand, & Fossum, 2009; Kanaya et al., 2005; Kleiman, 2000; Mouza, 2002; Swan et al., 2005).

Duration

Research has indicated that it takes a great deal of time for teachers to fully master a new skill, and most teachers do not receive the recommended amount of professional development necessary to master new skills (Darling-Hammond et al., 2009; Kleiman, 2000). Darling-Hammond et al.'s (2009) summary of the literature about effective professional development found that professional development opportunities that averaged 49 hours in duration were related to an average student achievement gain of 21 percentile points. As such, they suggested that teachers generally need about 50 hours of professional development to affect their skill.

Kanaya et al.'s (2005) study of 237 teachers participating in Intel Teach to the Future, a professional development program that focuses on the integration of the use of software into instruction, found that the length of professional development was a predictor of the implementation of technology-rich lessons. However, Kanaya et al. (2005) found that "compressed" length professional development was more likely to result in teachers implementing technology than "extended" length professional development. Completion of a "standard" length professional development (45-95 days) was associated with a 200% increase in the odds of implementing a technology-rich lesson, and completion of a "compressed" length professional development (0-44 days) was associated with a 300% increase in the odds of implementing a technology rich lesson as compared to an "extended" length professional development (96 days). This finding suggests that professional development offered over a shorter period of time may be more effective at encouraging implementation.

Despite the potential for positive outcomes, many teachers do not receive the recommended amount of professional development. Shapley et al.'s (2010) study of the Technology Immersion model in 21 schools in Texas found that teachers at most schools had received only minimal or partial levels of professional development by the fourth year of implementation. Teachers had received less than 38 hours of professional development, on average, in year four. Darling-Hammond et al. (2009) found that less than half of teachers reported receiving more than 16 hours of professional development in their content area in the past year, and only 13.4% reported receiving more than 16 hours of professional development on using computers in instruction.

Zucker and Hug's (2007) study of the one-to-one project at The Denver School of Science and Technology identified similar findings. Their survey of participating teachers revealed that 95% reported that professional development in technology was useful or somewhat useful, although only 10% reported that they had received 16 hours or more of training. Likewise, teachers participating in the Maine Learning Technology Initiative indicated that the lack of sufficient professional development was one of the greatest barriers to utilizing technology in the classroom (Silvernail & Harris, 2003).

Collaboration

Research routinely finds that teachers who collaborate with each other have greater success implementing new technology in the classroom. A study of a professional development program designed to help pre-service science teachers learn to use instructional technology, for example, found that collaborative partnerships increased teachers' motivation to implement technology in the classroom (Duran et al., 2009). Swan et al.'s (2005) study of eight teachers' experiences with a professional development program also identified changes in teaching practices. In the program, teachers brought their classes to a ubiquitous computing environment for a half day every day for six weeks. Participating teachers collaborated with each other and professional development staff to integrate the use of technology into instruction. Over the course of the study, teachers' level of technology integration, as measured by a self-report instrument, increased an average of one and a half stages on an eight point scale.

The evaluation of the Maine Learning Technology Initiative found that teachers rated most forms of professional development to be effective or very effective. Interestingly, the evaluation revealed that "informal help from colleagues" received more "effective" or "very effective" ratings than the Maine Learning Technology Initiative (Silvernail & Harris, 2003), suggesting that teachers received the most benefit by working together collaboratively. Similarly, Mouza's (2002) case study suggested teachers should have time to discuss new technologies with colleagues to derive the most benefit, and teachers in Shapely et al.'s

(2010) study reported that the lack of sufficient time to collaborate was one of the biggest barriers to technology integration.

Relevance

Other studies have identified the applicability of the topics presented in professional development to teachers' day-to-day instruction as an important factor in the implementation of technology in the classroom. Kanaya et al.'s (2005) study of the Intel Teach to the Future program showed that the usefulness of the pedagogy covered in professional development was a predictor of the use of new software applications and of the implementation of technology-rich lessons. Darling-Hammond et al.'s (2009) review of the literature suggested that professional development is most effective when it covered topics specific to a teacher's subject area, and Goos and Bennison (2008) found that professional development that modeled the use of technology in instruction was particularly beneficial to teachers. Similarly, Mouza's (2002) case study suggested that professional development in technology should reflect the realities of the classroom.

Technical Difficulty

There is no consensus as to the best method of introducing teachers to new technology. Ertmer (2005) suggested that teachers need to be introduced to simple uses of technology in order to establish a pattern of use. She argued that simple and straightforward uses of technology are the best ways to elicit change in teaching practices. She reasoned that teachers' belief in the value of technology as an instructional tool can expedite or impede the use of technology in the classroom.

However, Cuban (2001) claimed that professional development that focuses on simple uses of technology is not related to changes in instructional practice. It is possible that the profusion of teachers using computers for “uninspired” purposes were graduates of the “simple and straightforward” approach. Further, a study of teachers participating in technology-oriented professional development reported a need for more complex professional development, as the professional development being offered was too simplistic for their level of technical proficiency (Judge & O’Bannon, 2004).

Lack of Adequate Access

Despite the potential benefits of participation in professional development in technology, teachers’ access to professional development is not consistent across schools. Wenglinsky (1998) found that teachers of urban and rural students were less likely to have received professional development in technology than teachers of suburban students. Further, Darling-Hammond et al. (2009) found that secondary school teachers were less likely to participate in professional development than elementary school teachers. As discussed earlier in this section, even recipients of professional development in technology often do not receive the quantity or quality necessary to improve their skills (Darling-Hammond et al., 2009; Kleiman, 2000; Shapley et al., 2010; Silvernail & Harris, 2003; Zucker & Hug, 2007). This problem is exacerbated by the disparate opportunities to engage in professional development in technology across schools and districts. Cultivating a greater understanding of the relationship between teachers’ professional development in technology and student achievement helps with the creation of professional development that is timely, relevant, and effective.

Chapter Summary

This chapter provided an overview of research on the relationship between the use of technology in instruction and student achievement. The use of technology in instruction, particularly mathematics instruction, is low. When technology is being employed in the classroom, it is most often for mundane and/or lower-order tasks. This chapter also discussed the relationship between that the use of technology in mathematics instruction and student achievement. Although numerous studies have identified a positive relationship, others have identified a negative relationship, making it difficult to draw any conclusions about the relationship between technology and student achievement. Research on other measures of the effectiveness of technology, such as student engagement, was shared. This chapter also included a summary of the relationship between students' use of a computer at home, which has generally been found to be positively related to student achievement, and the different relationship between technology use and achievement for male and female students. The chapter concluded with an overview of research on the usefulness of teachers' professional development and its relationship to the use of technology in instruction.

CHAPTER 3

Methodology

Introduction

This chapter describes the method of analysis that was used to answer the research questions guiding this study. The purpose of this study is to examine the relationship between the use of computer technology in mathematics classrooms and student achievement in mathematics across a wide spectrum of students and schools. Of particular interest are the roles that the gender of the student, teachers' exposure to professional development in technology, and specific uses of computer technology play in the relationship between the use of computer technology in mathematics and student achievement in mathematics. This chapter explains the selection of the dependent and independent and control variables and provides descriptive statistics for each variable. The chapter concludes with a discussion of the primary method of analysis for this study, multilevel modeling (MLM). The results of analyses are presented in Chapter 4.

There is a great deal of research on the relationship between the use of technology in instruction and student outcomes, such as student achievement (e.g., Bebell & Kay, 2010; Campuzano et al., 2009; Hunter & Greever-Rice, 2007; Shapely et al., 2010). However, most of that research follows a specific technological initiative in the school or classroom. Analyzing the ELS:2002 dataset provides an indication of the relationship between instructional practices using computer technology and student achievement, regardless of whether the student has participated in a specific technological intervention. In addition, using the ELS:2002 dataset, which is comprised of a randomly selected sample of the general student population, for this study ensures that the results are more reflective of and generalizable to the student population at large.

This quasi-experimental quantitative study seeks to determine the relationship between the use of computer technology in the classroom, as reported by students, and student achievement in mathematics. In particular, this study focuses on how the relationship between computer technology use and student achievement differs by gender. Three research questions serve as a guide for the study:

1(a): What is the relationship between the frequency of use of computer technology in mathematics classes and student achievement in mathematics?

1(b): Does the relationship between the frequency of use of computer technology in mathematics classes and student achievement vary by the gender of the student?

2(a): What is the relationship between specific types of use of computer technology in mathematics classrooms and student achievement in mathematics?

2(b): Does the relationship between specific types of use of computer technology in mathematics classrooms and student achievement vary by the gender of the student?

3(a): What is the relationship between mathematics teachers' professional development in technology and student achievement in mathematics?

3(b): Does the relationship between mathematics teachers' professional development in technology and student achievement in mathematics differ by the gender of the student?

Data Source

The data for this study comes from the ELS:2002 (Ingels et al., 2007), collected by the National Center for Education Statistics (NCES). The data were collected from students and teachers in 2002, when the students were in their sophomore year of high school. The base year data includes demographic information about students and teachers, measures of student achievement, and data regarding students' experiences in school. The sample includes a nationally representative sample of schools, selected using stratified probability proportional to size. A total of 752 schools participated in the study (Ingels et al., 2007). Approximately twenty six students were selected at random from a stratified sample within each school. Of the 17,591 students selected, 15,362 completed the base year questionnaire. In addition, each student's mathematics teacher was asked to complete a questionnaire. In total, the base year questionnaire was completed by 12,543 mathematics teachers.

Student-level Variables

Dependent Variable

The dependent variable for this model is students' standardized score on the mathematics test administered for ELS. The mathematics test assessed students' knowledge of arithmetic, algebra, geometry/measurement, data/probability, analytic geometry, and pre-calculus (Ingels et al., 2007). Test questions were pulled from assessments administered for the NELS:88, the NAEP, and the PISA. The base-year mathematics assessment was administered specifically for the ELS:2002. It included a total of 73 items, which consisted of predominantly multiple-choice items with approximately 10% open-ended items.

Students' standardized scores on the mathematics test (BYTXMSTD) ranged from

19.38 to 86.68 (Ingels et al., 2007). The average (unweighted) score was 50.74 with a standard deviation of 9.98. The decision to focus only on student achievement as measured by their standardized score on a mathematics test was based on the available data in the ELS:2002 dataset. Students who reported that they used computer technology in their mathematics class were asked more comprehensive questions about the manner in which technology was being used. Students were not asked the same questions about the use of technology in their English classes. Focusing on student achievement in mathematics as the outcome variable of interest permits a more in-depth analysis of the relationship between the use of computer technology and student achievement (i.e. Research Question 2).

Independent Variables

When investigating relationships involving students' educational outcomes, it is important to control for the influence of potentially confounding variables. Some of the variables included in the model describe the demographic composition of the student, reported by the student on the student questionnaire, including the gender of the student (BYSEX), the student's race/ethnicity (BYRACE), and the student's socioeconomic status (BYSES2). Gender (BYSEX) was recoded such that male students were represented by 0 and female students were represented by 1. Male and female students each represent approximately half of the student population (49.8% and 50.2%, respectively). Race/ethnicity (BYRACE) was recoded into five dummy-coded groups (American Indian, Asian, Black, Hispanic, and Multiracial), with White as the referent group. The socioeconomic status of the student (BYSES2) is a composite measure constructed from information gathered from the parent questionnaire regarding the student's father's/guardian's education, mother's/guardian's education, family income, father's/guardian's occupation, and mother's/guardian's occupation. This measure differs from the other measure of socioeconomic status in the ELS:2002 dataset, BYSES1, in that it uses a more recent measure of occupational prestige (the 1989 GSS rather than the 1961 Duncan). Frequencies or means and standard deviations for each of the demographic measures are presented in Table 3.1.

Table 3.1

Unweighted Frequencies and Means for Student-level Demographic Variables

Variable	Label	Category	Range	Mean	SD	Frequency
BYTXMSTD	Math test standardized score		19.38-86.68	50.74	9.98	
BYSEX	Sex composite	Male				49.8
		Female				50.2
BYRACE	Student's race/ethnicity composite	Am. Indian				0.8
		Asian				9.6
		Black				13.2
		Hispanic				14.5
		Multiracial				4.8
		White				57.0
BYSES2	Socio-economic status composite			0.04	0.75	
BYS29H	How often uses computers in math class		1-5	1.79	1.24	
BYS31A	How often uses computers to review math work		1-5	1.16	0.64	
BYS31B	How often uses computers to solve math problems		1-5	1.28	0.86	
BYS31C	How often uses computers for graphing in math class		1-5	1.22	0.73	
BYS31D	How often uses computers to practice math drills		1-5	1.25	0.80	
BYS31E	How often uses computers to analyze data in math class		1-5	1.21	0.71	
BYS31F	How often uses computers to apply learning in math class		1-5	1.27	0.82	

Table 3.1 (continued)

Variable	Label	Category	Range	Mean	SD	Frequency
BYS31G	How often math teachers uses computer to instruct one-on-one		1-5	1.15	0.61	
BYS31H	How often math teacher uses computer to show new topics		1-5	1.21	0.73	
BYS47A	How often student uses computer at home		1-5	4.05	1.31	
BYTM38A	Received training in basic computer skills.	Yes				80.3
BYTM38B	Received training in software applications.	Yes				81.8
BYTM38C	Received training in use of Internet.	Yes				79.5
BYTM38A	Received training in use of other technology.	Yes				41.5
BYTM38E	Received training in integrating technology in curriculum.	Yes				75.6
BYTM38F	Received follow-up or advanced training.	Yes				44.4
BYSCTRL	School control	Public				78.6
		Catholic				12.5
		Other private				8.9
BYURBAN	School urbanicity	Urban				33.3
		Suburban				48.2
		Rural				18.5
BY10FLP	Grade 10 percent free lunch	0-5				32.6
		6-10				9.3
		11-20				16.7
		21-30				12.5
		31-50				14.6
		51-75				8.7
		76-100				5.6

This study addresses the first research question by analyzing the relationship between the frequency with which computers are used in students' mathematics classes (BYS29H) and student achievement in mathematics. Students were asked, "In your current or most recent mathematics class, how often did you use computers?" Answer choices were "Never", "Rarely", "Less than once a week", "Once or twice a week", and "Every day or almost every day". Responses were coded such that a "Never" response is represented by 1, "Rarely" is represented by 2, "Less than once a week" is represented by 3, "Once or twice a week" is represented by 4, and "Every day or almost every day" is represented by 5. The mean and standard deviation for this item is presented in Table 3.1.

This study addresses the second research question by looking at the relationship between the manner in which the students and/or the teacher are using computers in mathematics class (BYS31A-H) and student achievement. Students were asked "In your current or most recent mathematics class, how often do/did you use computers in the following ways?" The follow-up prompts were: "Review work from the previous day," "To work problems or problem solving activities," "For graphing," "To practice math drills," "To analyze data," "To apply what was learned in class to new situations or problems," "The teachers uses/used the computer to instruct us individually," and "The teacher uses/used the computer to demonstrate new topics in mathematics." Answer choices were "Never," "Rarely," "Less than once a week," "Once or twice a week," and "Every day or almost every day." Responses were coded such that a "Never" response is represented by 1, "Rarely" is represented by 2, "Less than once a week" is represented by 3, "Once or twice a week" is represented by 4, and "Every day or almost every day" is represented by 5.

Approximately 85% of students skipped this item because they indicated that they did not use a computer in their current or most recent mathematics class (Ingels et al., 2007). These responses, which were coded as a legitimate skip, were recoded as a 1, or “Never”, response for the purposes of this study. The means and standard deviations for these items are presented in Table 3.1.

This study controls for students’ use of a computer at home, as measured by BYS47A. BYS47A asked students, “How often do you use a computer . . .” The prompt of interest was “at home?” Answer choices were “No computer”, “Never”, “Less than once a week”, “Once or twice a week”, and “Every day or almost every day”. To more accurately measure the relationship between the frequency of use of a home computer and student achievement, responses “No computer” and “Never” were merged, as they both reflect the absence of the use of a computer at home. Approximately 11% of students reported that they did not have a computer at home. “No computer/Never” is represented by 1, “Less than once a week” is represented by 2, “Once or twice a week” is represented by 3, and “Every day or almost every day” is represented by 4. The frequency of responses for this variable is presented in Table 3.1.

This study addresses the third research question by investigating the relationship between the specific type of professional development in technology mathematics teachers received (BYTM38A-F) and student achievement. This item asked teachers, “In the last 3 years, have you received training in these areas from any source?” Sources included “Basic computer training”, “Software applications”, “Use of the Internet”, “Use of other technology (e.g., satellite access, wireless Web, interactive video, closed-circuit TV, videoconferencing)", "Integration of computers and other technology into the classroom curriculum", and "Follow-up or advanced training". Answer choices were dichotomous: "Yes" or "No". The frequencies of responses for these variables are displayed in Table 3.1.

School-level Variables

This model also incorporates variables that describe students' schools. Such variables include the urbanicity of the school (BYURBAN), the type of school (public or private, BYSCTRL), and the percentage of students at the school receiving free or reduced-price lunch (BY10FLP). BYURBAN, provided by the Common Core of Data 1999-2000 and the Private School Survey 1999-2000, was recoded into two dummy variables, urban and rural. Schools located in suburban areas serve as the referent group. About half (48.2%) of the schools in the sample were located in a suburban area, 33.3% of the schools were located in an urban area, and 18.5% of the schools were located in a rural area.

BYSCTRL, provided by the provided by the Common Core of Data 1999-2000 and the Private School Survey 1999-2000, was recoded into a two dummy variables, Catholic and Non-Catholic private. Public schools served as the referent group. The majority of schools (78.6%) were public. BY10FLP, which measures the percentage of free lunch students in 10^{th} grade at the school as reported by the school's administrator, was recoded into several dummy variables (FRL0to5, FRL6to10, FRL11to20, FRL21to30, FRL51to75, FRL7to100). Schools with 31 to 50% of 10^{th} grade students receiving free lunch served as the referent group. Frequencies for each of the school-level variables are presented in Table 3.1.

Data Analysis

The first stage of analysis consists of descriptive statistics used to identify differences among students and schools. The means, standard deviations, and frequencies, when appropriate, of each independent variable of interest (i.e., frequency of computer use, review math work, solve math problems, graphing, math drills, analyze data, apply learning, instruct one-on-one, show new topics, training in basic computer skills, training in software applications, training in use of Internet, training in other technology, training in integrating technology, and advanced training) were calculated for both male and female students. This analysis provides valuable insight into how the use of computers in mathematics classrooms varies by gender. PASW (SPSS) version 18 is used to generate descriptive statistics for this study.

The second stage of analysis involves the use of multilevel modeling (MLM), also known as hierarchical linear modeling (HLM). MLM is used to determine the relationship between the independent variables and student achievement as measured by students' standardized score on the mathematics test. Because the outcome variable is students' standardized score on the mathematics test, students who did not complete the mathematics test or had a legitimate skip (-8) on the mathematics test were listwise deleted from the sample, as were students who did not fill out the base year student questionnaire. To abide by best practices of MLM, schools with fewer than five students were also removed from the sample. The resulting dataset consisted of 15,295 students and 743 schools.

MLM was selected as the method of analysis based on a number of factors. First, educational data is naturally nested, consisting of students within classrooms within schools.

The multilevel model framework uses a two- or three-level hierarchical model to represent variability, allowing for estimates of between-group and within-group variability (Raudenbush & Bryk, 2002). MLM accounts for the possible influence of the grouping agent (which in this study is the school), thus allowing estimates of contextual effects (Bickel, 2007).

Another benefit of MLM is that it can manage unbalanced data (Raudenbush & Bryk, 2002). Although a more or less equal number of students were sampled at each school, the deletion of cases in which students did not complete the mathematics exam resulted in a somewhat unbalanced dataset, meaning that the resulting dataset included an unequal number of students at each school. And finally, each research question involves both student-level and school-level variables and their relationship to a student-level outcome. For these reasons, analyzing the data at the school level or the student level alone would be inappropriate.

Centering data is fairly common in MLM analyses. A benefit of centering variables is that it makes the parameter estimates more interpretable. Centering also reduces multicollinearity by accounting for highly correlated predictors (Morrell, Pearson, & Brant, 1997; Raudenbush & Bryk, 2002; Tabachnick & Fiddell, 2007). Grand-mean centering is fairly straightforward: the sample mean is subtracted from each data point in the sample. All non-dichotomous independent variables in the model were grand-mean centered prior to MLM analysis.

The students included in the ELS:2002 dataset represent a deliberate oversampling of students at private schools as well as Asian and Hispanic students to ensure that these subgroups were adequately represented. Such oversampling can result in an increased probability of Type I error. The application of the appropriate sampling weights adjusts for this oversampling and mitigates the increased risk of Type I error (Hahs-Vaughn, 2005). The appropriate weights are applied to the data throughout the analysis.

Missing data presents a few challenges to analyzing the ELS:2002 dataset. Approximately 8 to 10% of student responses to items related to computer use at school were missing. About 6% of responses related to the use of a computer at home were missing, and approximately 16% of the responses to the variables related to teachers' professional development on the use of computers were missing. However, the sample size is still sufficiently large enough to discern significance, and the subgroup sample sizes are of sufficient size to be generalizable.

Data that are not missing at random present a challenge to analysis. There is no consensus in the literature as to the best way to handle missing data without compromising the integrity of the dataset. Both ignoring the missing data and imputing the data may affect the results of the analysis. Missing data were analyzed using PASW (SPSS) version 18 to determine if the data was missing completely at random (MCAR), missing at random (MAR), or not missing at random. As discussed in detail in Chapter 4, separate analyses were run: (a) missing data were both imputed and (b) listwise deleted from the study.

In this study, students (level 1) are nested within schools (level 2). Teachers' professional development in technology is analyzed at the student level, as there are no codes in the ELS:2002 dataset to allow for the evaluation of data at the teacher level. This study analyzes a single model to investigate the relationship between the use of computer technology in the classroom, teachers' professional development in technology, and student achievement. Multilevel modeling looks at how these relationships vary among students within a school and how these relationships vary across schools. While the variables of interest for this study are all at the student level (level 1), it is important not to disregard the contextual effect of the school. A diagram of the variables analyzed in this study is shown in Figure 3.1.

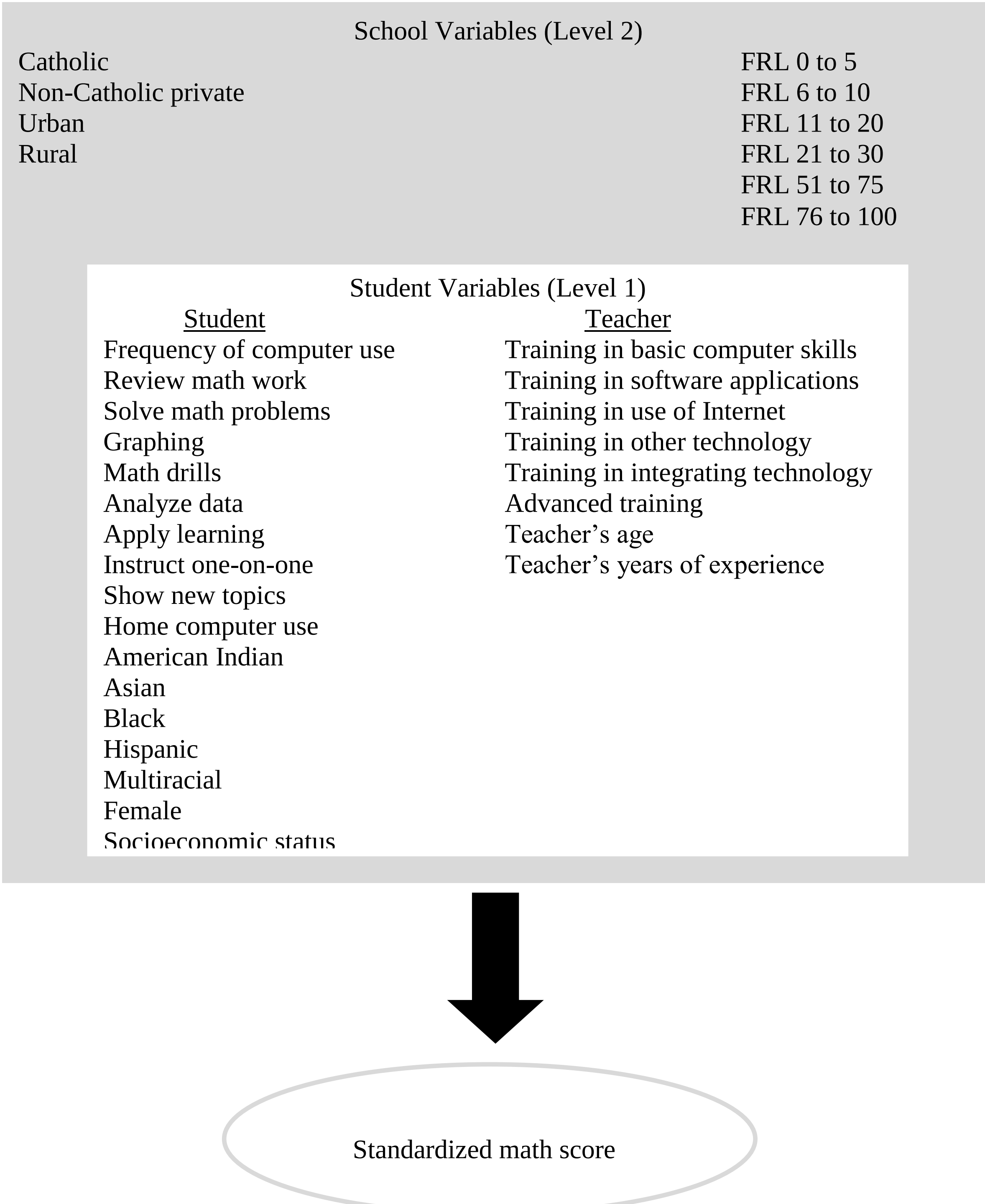

Figure 3.1. Diagram of study variables
Note. It was not possible to cluster students within teachers due to the lack of appropriate codes in ELS:2002.

A preliminary analysis of the data was evaluated first to determine if there was sufficient variability at level 2 to conduct further analysis (Raudenbush & Bryk, 2002). This analysis, referred to as the null model (or the fully-unconditional model), contained the dependent variable and no independent variables. The following equation represents the null model, in which no predictors are present:

Level 1: $\text{BYTXMSTD} = \beta_{0j} + r_{ij}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

The intercept, $\beta_{0,}$ is the expected value of the mathematics test standardized score when no independent variables are taken into account. The grand mean (average across schools) of the mathematics test standardized scores is represented by γ_{00}. The within-school variability is represented by r_{ij}, and the between school variability is represented by u_{0i}. The *i* represents the student, and the *j* represents the school.

The multilevel models seek to establish the overall relationship between the frequency of use of computers in mathematics instruction, mathematics teachers' exposure to professional development in technology, and student achievement as measured by the students' standardized scores on the mathematics test. If the null model identifies sufficient variability at both levels, non-randomly varying slopes models are compared with the null model. This model allows for the inclusion of covariates at both level 1 and level 2.

The full model addresses all three research questions with the inclusion of all key independent variables, including frequency of computer use (BYS29H), review math work (BYS31A), solve math problems (BYS31B), graphing (BYS31C), math drills (BYS31D), analyze data (BYS31E), apply learning (BYS31F), instruct one-on-one (BYS31G), show new topics (BYS31H), training in basic computer skills (BYTM38A), training in software applications (BYTM38B), training in use of the Internet (BYTM38C), training in other technology (BYTM38D), training in integrating technology (BYTM38E), and advanced training (BYTM38F). The model also investigates the interaction between gender and home computer use (BYS47A), gender and frequency of computer use at school, and gender and students' teachers' exposure to professional development in technology. This model allows for a complete exploration of the relationships between student achievement in mathematics, students' use of computers in mathematics, and teachers' professional development in technology. Including all key variables in the same model allows for an examination of the big picture, acknowledging the influence the variables may exert on each other.

The model was run twice–once with no school level predictors and once with all (level 1 and level 2) predictors. It was important to exclude the school level predictors to allow a comparison of student achievement with and without the controls at the school level. The full model includes all level 1 variables, and also controls for school level variables: (a) the urbanicity of the school (BYURBAN), (b) the type of school (BYSCTRL), and (c) the percentage of students in the 10^{th} grade at the school that receive free lunch (BY10FLP). The equation for the full model is represented by:

Level 1: Math Standardized Scale Score = β_{0ij} + β_{1j}(Female) + β_{2j}(AmIndian) + β_{3j}(Asian) + β_{4j}(Black) + β_{5j}(Hispanic) + β_{6j}(Multiracial) + β_{7j}(SES) + β_{8j}(Frequency of Computer Use) + β_{9j}(Review Math Work) + β_{10j}(Solve Math Problems) + β_{11j}(Graphing) + β_{12j}(Math Drills) + β_{13j}(Analyze Data) + β_{14j}(Apply Learning) + β_{15j}(Instruct One-on-One) + β_{16j}(Show New Topics)

$+ \beta_{17j}$(Home Computer Use) + β_{18j}(Training in Basic Computer Skills) + β_{19j}(Training in Software Applications) + β_{20j}(Training in use of Internet) + β_{21j}(Training in Other Technology) + β_{22j}(Training in Integrating Technology) + β_{23j}(Advanced Training) + β_{24j}(Female*Frequency of Computer Use) + β_{25j}(Female*Review Math Work) + β_{26j}(Female*Solve Math Problems) + β_{27j}(Female*Graphing) + β_{28j}(Female*Math Drills) + β_{29j}(Female*Analyze Data) + β_{30j}(Female*Apply Learning) + β_{31j}(Female*Instruct One-on-One) + β_{32j}(Female*Show New Topics) + β_{33j}(Female*Home Computer Use) + β_{34j}(Female*Training in Basic Computer Skills) + β_{35j}(Female*Training in Software Applications) + β_{36j}(Female*Training in use of Internet) + β_{37j}(Female*Training in Other Technology) + β_{38j}(Female*Training in Integrating Technology) + β_{39j}*(Female*Advanced Training) + r_{ij}

Level 2: $\beta_{0j} = \gamma_{00} + \gamma_{01}$(Urban) + γ_{02}(Rural) + γ_{03}(Catholic) +γ_{04}(NonCatholicPrivate) + γ_{05}(BYFLP0to5) + γ_{06}(BYFLP6to10) + γ_{07}(BYFLP11to20) + γ_{08}(BYFLP21to30) + γ_{09}(BYFLP51to75) + γ_{010}(BYFLP76to100) + u_{0j}

$\beta_{qj} = \gamma_{q0}$ for each q =1 to 39

In this model, γ_{00} is the grand mean of students' mathematics standardized test scores when all predictors equal zero, at school *j* and student *i*; r_{ij} represents the residual within-school variance in students' mathematics scores; and u_{0i} represents the between-school variability in students' mathematics scores, which is associated with the τ_{00} statistic, after accounting for the effects of the predictors. The full model includes additional γ_{010} components, which represent the between-school differences in students' mathematics scores as a function of the respective level 2 predictor, after accounting for the other level 2 variables. For example, γ_{01} is the between-school variability in students' mathematics scores as a function of the urbanicity of the school, after accounting for the type of school (public, Catholic, or non-Catholic private) and the level of poverty at the school (based on the percentage of students at the school receiving free or reduced-price lunch).

The use of MLM to investigate these relationships allows for an exploration of these variables while accounting for the contextual effects of the school. This is particularly beneficial in educational research, as an outcome like student achievement is influenced by factors at both the student and the school level. In the case of this study, the full model seeks to identify how students' use of computers in their mathematics class is related to student achievement in mathematics. MLM allows for an investigation of how this relationship may vary across schools while controlling for school-level variables, such as the poverty of the school. The study also seeks to identify the relationship between mathematics teachers' exposure to professional development in technology and student achievement in mathematics. Again, MLM allows an investigation of this relationship while identifying how the relationship varies across schools. Such an investigation may reveal important information about differing outcomes across different educational contexts.

Chapter Summary

This chapter described the data source, variables of interest and the procedures guiding statistical analyses conducted to answer the research questions. Multilevel modeling (MLM) was selected as the primary means of analysis to account for the nested nature of the data (students within schools). The benefits of using MLM include its ability to account for the influence of the grouping agent, which in this case is the school, and its ability to manage unbalanced data. The decision to grand-mean center all non-dichotomous independent variables was shared. The data source, the ELS:2002 (Ingels et al., 2007), which reflects a nationally representative sample of high school sophomores, was discussed. The decision to weight the data to adjust for the oversampling of specific groups of students was shared, as was the plan to investigate missing data. The equation for the null/fully unconditional model and the equation for the full model were presented. The full model includes key independent variables that will address research questions one, two, and three. Findings of this study are presented in Chapter 4, and a discussion of the implications of those findings is presented in Chapter 5.

CHAPTER 4

Results

Introduction

The purpose of this study is to examine the relationship between the use of computer technology in instruction and student achievement in mathematics across a wide spectrum of students and schools. Of particular interest is the relationship between the gender of the student, teachers' exposure to professional development in technology, specific uses of computer technology, and student achievement in mathematics. Three research questions guide this study:

1(a): What is the relationship between the frequency of use of computer technology in mathematics classes and student achievement in mathematics?

1(b): Does the relationship between the frequency of use of computer technology in mathematics classes and student achievement vary by the gender of the student?

2(a): What is the relationship between specific types of use of computer technology in mathematics classrooms and student achievement in mathematics?

2(b): Does the relationship between specific types of use of computer technology in mathematics classrooms and student achievement vary by the gender of the student?

3(a): What is the relationship between mathematics teachers' professional development in technology and student achievement in mathematics?

3(b): Does the relationship between mathematics teachers' professional development in technology and student achievement in mathematics differ by the gender of the student?

This chapter presents the results of the analysis of data. Specifically, the first three sections describe data cleaning procedures, including a description of analyses of distributions and bivariate correlations. The problem presented by weighting and missing values is discussed, and the final section presents the findings of the MLM models developed to address each of the research questions guiding this study.

Testing Assumptions

Prior to running the models, each non-dichotomous variable was analyzed to determine its distribution. Although many of these variables reflect discrete responses to a Likert scale, and thus are not continuous variables, it is still important to test that the distribution is close to normal (i.e., mound-shaped). To determine if the variables had a normal distribution, values for skewness and kurtosis were calculated, and histograms were graphed. Skewness is defined as the measure of symmetry in a distribution. Variables that exhibit skew have “tails” to the left (negative) or right (positive), indicating an abnormal concentration of responses at one extreme. Kurtosis is defined as a measure of the flatness of a distribution, indicating too many or too few cases in the tails (Tabachnick & Fidell, 2007). As seen in Table 4.1, the variables related to the specific applications of computers in mathematics classes (BYS31A-H) exceeded accepted standards of skewness and kurtosis. Histograms of each non-dichotomous independent variable can be found in Appendix A.

Table 4.1

Level-1 Descriptive Statistics, Unweighted

	N	Range	Mean	SD	Skewness		Kurtosis	
					Statistic	Std. error	Statistic	Std. error
Freq. of comp. use	14,087	1-5	1.79	1.24	1.55	.02	1.17	.04
Review math work	13,721	1-5	1.16	0.64	4.66	.02	22.15	.04
Solve math problems	13,992	1-5	1.28	0.86	3.26	.02	9.82	.04
Graphing	13,682	1-5	1.22	0.73	3.68	.02	13.45	.04
Math drills	13,925	1-5	1.25	0.80	3.46	.02	11.38	.04
Analyze data	13,657	1-5	1.21	0.71	3.82	.02	14.51	.04
Apply learning	13,902	1-5	1.27	0.82	3.31	.02	10.33	.04
Instruct one-on-one	13,699	1-5	1.15	0.61	4.64	.02	22.25	.04
Show new topics	13,925	1-5	1.21	0.73	3.83	.02	14.47	.04
Home computer use	14,271	1-4	3.15	1.09	-0.95	.02	-0.52	.04
Teach. age	12,848	23-67	43.01	11.37	-0.02	.02	-1.16	.04
Teach. years of exp.	12,793	0-40	14.89	10.72	0.53	.02	-0.92	.04

Items related to the specific applications of computers in the classroom (BYS31A-H) were far outside the acceptable range of skewness and kurtosis due to the large percentage of students responding that they never used computers in the classroom. Attempts at transforming these variables using conventional methods (logarithmic and square root transformations) did not result in normally distributed (or mound-shaped) variables; the values of skewness and kurtosis still exceeded the values commonly accepted as tolerable. Three choices remained in moving forward with the analysis:

1) Using only responses from those students who indicated in their response to item BYS29H that computers were used in the classroom in some capacity (those not responding “never”). This approach would diminish the responses to the variables of interest (i.e., BYS31A-H) by approximately 85%.

2) Violating the assumption of normality and using the non-normal variables as is in the analysis. This approach runs the risk of reporting inaccurate coefficients and measures of significance for the variables of interest (i.e., BYS31A-H).

3) Restructuring the variables of interest into dichotomous variables, with responses of "never" coded as 0 and responses of "rarely", "less than once a week," "once or twice a week," and "everyday or almost everyday" coded as 1. This approach removes a degree of precision in the analysis of the use of computers.

The decision was made to follow the third approach and dichotomize the variables measuring the applications of computers. Although this approach reduced the precision of these variables, it was determined to be a better course of action than violating a primary assumption of regression analysis or diminishing the sample size by over 80%. A comparison of these variables, in their original (1-5) and their dichotomized (0 = never and 1 = otherwise) form, is presented in Table 4.2.

Table 4.2

Descriptive Statistics, Applications of Computers Variables (BYS31A-H), Unweighted

		Original		Dichotomous	
	N	Mean	SD	Mean	SD
Review math work	13,721	1.16	.64	0.08	.26
Solve math problems	13,992	1.28	.86	0.12	.33
Graphing	13,682	1.22	.73	0.11	.31
Math drills	13,925	1.25	.80	0.11	.32
Analyze data	13,657	1.21	.71	0.10	.30
Apply learning	13,902	1.27	.82	0.12	.33
Instruct one-on-one	13,699	1.15	.61	0.08	.27
Show new topics	13,925	1.21	.73	0.10	.30

Note: For dichotomous variables, the mean indicates the percentage of responses of "1" (i.e., the presence of the activity)

Weighting

The ELS:2002 dataset presents a special challenge to analysis: the students included in the ELS:2002 dataset represent a deliberate oversampling of students at private schools, as well as Asian and Hispanic students. The variables BYSTUWT and BYSCHWT, calculated in the base year, adjust for this oversampling (Ingels et al., 2007). The application of these weights mitigates the potential for an increased risk of Type I error (Hahs-Vaughn, 2005). The appropriate weights were applied to the data for the covariate, descriptive, and multilevel modeling analysis.

Measures of Association

Another key assumption of multivariate analysis is that there is a lack of multicollinearity among variables in the data. A high association between predictors could indicate that the predictors represent measures of the same information, which may alter the reliability and interpretability of the analysis. Analysis of tolerance and the variance-inflation factor (VIF) assess multivariate multicollinearity. Tolerance values less than 0.20 and VIF values greater than 4 indicate a problem with multicollinearity (Garson, 2010).

Among level 1 (student) variables, tolerance values ranged from 0.22 to 0.99, all above the threshold of concern for multicollinearity. However, four measures of the application of computers in the classroom returned VIF values greater than 4: how often uses computers to solve problems (4.19), how often uses computers to practice math drills (4.19), how often uses computers to analyze data in math class (4.20), and how often uses computers to apply learning in math class (4.50). Although these VIF values indicate the presence of multicollinearity, the tolerance values for these variables are acceptable. Because these variables reflect the application of computers in mathematics instruction, it is not surprising that relatively strong relationships were identified between them. However, it was important to retain each of these variables in the model, as the investigation of research question two required an investigation of the different applications of computers in the classroom. Analyzing a composite variable would reduce the ability to identify the relationship between specific applications of computers and student achievement. However, for the sake of thoroughness, results of a model with the applications of computers variables reflected in a single composite variable are provided in Appendix I. Further, all non-dichotomous variables were centered prior to analysis, reducing the influence of correlated variables on the analysis.

In the case of multilevel modeling, multicollinearity is a greater concern at level 2 (school) than at level 1. At level 2, all variables were dummy variables created from three variables: school urbanicity (urban, rural, suburban); school type (public, Catholic, or non-Catholic private); and the percentage of students at the school receiving free or reduced-price lunch (grouped into non-interval categories). Tolerance values for level 2 variables ranged from 0.45 to 0.88, and all VIF values were below 4, indicating no incidences of multicollinearity at level 2. Tolerance and VIF values for both level 1 and level 2 variables are presented in Appendix B.

Descriptive Statistics

An initial analysis of means and frequencies provides insight into patterns and disparities among the variables, particularly when statistics are calculated separately for male and female students. As shown in Table 4.3, the means of most independent variables were roughly equivalent for male and female students. Male students reported a greater average frequency of use of computers in mathematics than female students, and male students had a higher average standardized score on the mathematics test than females.

Table 4.3

Means and Standard Deviations of Dependent and Independent Variables, by Students' Gender

	Female			Male		
	N	Mean	SD	N	Mean	SD
Standardized math score	1,696,196	49.53	9.57	1,726,124	50.52	10.33
Review math work	1,569,627	1.72	1.18	1,583,497	1.86	1.29
Solve math problems	1,537,226	.07	0.26	1,532,911	.09	0.28
Graphing	1,566,890	.13	0.33	1,565,514	.14	0.34
Math drills	1,531,794	.11	0.31	1,528,575	.12	0.33
Analyze data	1,558,293	.11	0.32	1,558,746	.13	0.33
Apply learning	1,529,224	.10	0.30	1,528,243	.11	0.32
Instruct one-on-one	1,554,639	.12	0.36	1,557,271	.13	0.34
Show new topics	1,533,973	.07	0.26	1,531,111	.09	0.29
Review math work	1,561,356	.10	0.30	1,558,837	.11	0.32
Home computer use	1,601,366	3.08	1.10	1,600,345	3.10	1.12
Training in basic computer skills	1,398,944	.82	0.39	1,424,334	.82	0.38
Training in software applications	1,395,382	.84	0.37	1,421,763	.84	0.37
Training in use of Internet	1,393,554	.81	0.39	1,418,872	.81	0.39
Training in other technology	1,395,790	.42	0.49	1,422,338	.43	0.50
Training in integrating technology	1,402,036	.78	0.42	1,427,370	.79	0.41
Advanced training	1,392,419	.46	0.50	1,415,535	.48	0.50
Teacher's age	1,406,194	42.45	11.29	1,421,381	42.67	11.32
Teacher's years of experience	1,399,033	14.62	10.51	1,411,564	14.79	10.70

Because this study includes school-level predictors, it is important to investigate the variance in computer use across different types of schools. Table 4.4 presents the percent of students who reported using computers in mathematics, disaggregated by the urbanicity of the school. The frequency of use of computers was roughly equivalent at urban, suburban, and rural schools. Across all schools, male students reported greater use of computers, on average, than female students. However, the difference between the use of computers among male and female students was greatest at rural schools, with 62.7% of female students reporting that they never used a computer in mathematics, compared to 56.6% of male students.

Table 4.4

Frequency of the Use of Computers in Mathematics, by Urbanicity and Students' Gender

		Never	Rarely	Less than once a week	Once or twice a week	Everyday or almost everyday
Urban	Male	59.0%	19.0%	5.0%	7.6%	9.2%
	Female	60.5%	20.5%	6.3%	4.9%	7.8%
	Total	59.8%	19.8%	5.7%	6.3%	8.5%
Suburban	Male	59.2%	20.0%	6.2%	6.6%	8.0%
	Female	64.1%	20.0%	5.2%	4.6%	6.2%
	Total	61.6%	20.0%	5.7%	5.6%	7.1%
Rural	Male	56.6%	22.8%	5.6%	6.6%	8.4%
	Female	62.7%	20.6%	5.1%	6.0%	5.6%
	Total	59.6%	21.7%	5.4%	6.3%	7.0%

As depicted in Table 4.5, the frequency of computer use in mathematics varied slightly when disaggregated by the percentage of FRL students at the school. In general, students at schools with more than 30 percent of students qualifying for FRL used computers more frequently than students at schools with less than 30 percent of students qualifying for FRL. The greatest disparity in use by gender occurred in schools with 21 to 50 percent of students qualifying for FRL.

Table 4.5

Frequency of the Use of Computers in Mathematics, by School FRL and Students' Gender

		Never	Rarely	Less than once a week	Once or twice a week	Everyday or almost everyday
0-5 percent	Male	61.2%	22.1%	5.9%	4.6%	6.2%
	Female	63.2%	21.7%	6.5%	3.5%	5.2%
	Total	62.2%	21.9%	6.2%	4.1%	5.7%
6-10 percent	Male	63.5%	21.1%	5.7%	4.7%	5.1%
	Female	64.7%	20.8%	4.5%	5.6%	4.3%
	Total	64.1%	20.9%	5.1%	5.2%	4.7%
11-20 percent	Male	59.2%	19.4%	4.6%	8.2%	8.5%
	Female	61.9%	22.3%	5.2%	4.6%	6.0%
	Total	60.6%	20.9%	4.9%	6.4%	7.2%
21-30 percent	Male	59.6%	19.9%	6.5%	5.5%	8.5%
	Female	68.5%	16.3%	3.7%	5.0%	6.5%
	Total	63.9%	18.1%	5.1%	5.3%	7.5%
31-50 percent	Male	55.9%	19.0%	6.1%	7.8%	11.2%
	Female	63.6%	17.9%	5.6%	4.5%	8.5%
	Total	59.7%	18.5%	5.8%	6.2%	9.9%
51-75 percent	Male	51.2%	20.2%	6.4%	10.1%	12.1%
	Female	54.7%	21.0%	7.0%	8.8%	8.5%
	Total	52.9%	20.6%	6.7%	9.5%	10.3%
76-100 percent	Male	55.8%	16.6%	4.6%	10.1%	12.9%
	Female	56.3%	20.5%	7.6%	6.6%	9.0%
	Total	56.1%	18.6%	6.1%	8.3%	10.9%

As shown in Table 4.6, when disaggregated by school type (public, Catholic, or non-Catholic private), the use of computers in mathematics was greatest at public schools, with just under 40% of students reporting the use of computers at least "rarely." However, the disparity between male and female use of computers in mathematics was greatest at public schools, as well. Interestingly, female students at non-Catholic private schools indicated slightly more frequent use of computers than male students at non-Catholic private schools (by one percentage point).

Table 4.6

Frequency of the Use of Computers in Mathematics, by School Type and Students' Gender

		Never	Rarely	Less than once a week	Once or twice a week	Everyday or almost everyday
Public	Male	58.0%	20.4%	5.7%	7.2%	8.7%
	Female	62.5%	20.3%	5.4%	5.1%	6.7%
	Total	60.3%	20.3%	5.6%	6.1%	7.7%
Catholic	Male	66.9%	18.8%	6.3%	3.7%	4.3%
	Female	66.2%	20.0%	6.8%	2.6%	4.4%
	Total	66.5%	19.4%	6.5%	3.2%	4.3%
Non-Catholic Private	Male	64.8%	19.9%	4.9%	4.5%	5.9%
	Female	63.8%	20.2%	7.2%	4.2%	4.6%
	Total	64.3%	20.1%	6.0%	4.3%	5.2%

The characteristics of mathematics teachers may provide insight into patterns of computer use in the classroom. As presented in Table 4.7, an investigation of the frequency of use among teachers of different experience levels found that a smaller percentage of students with highly experienced teachers reported the use of computers in the classroom than students with less experienced teachers. Students of teachers with less than ten years of experience reported the greatest use of computers in the classroom, and students of teachers with over 35 years of experience reported the least use of computers in the classroom. Female students reported less use than male students across all experience levels but one:

female students of mathematics teachers with more than 35 years of experience reported more use of computers in the classroom than male students. The greatest disparity in use among male and female students occurred in the classrooms of teachers with 31 to 35 years of experience.

Table 4.7

Frequency of the Use of Computers in Mathematics, by Teachers' Years of Experience and Students' Gender

		Never	Rarely	Less than once a week	Once or twice a week	Everyday or almost everyday
0-5 years	Male	57.1%	21.3%	5.4%	6.9%	9.3%
	Female	60.8%	22.1%	4.6%	5.6%	6.7%
	Total	58.9%	21.7%	5.1%	6.3%	8.0%
6-10 years	Male	57.2%	21.4%	6.4%	8.2%	6.8%
	Female	58.6%	22.8%	6.9%	5.1%	6.5%
	Total	57.9%	22.1%	6.7%	6.6%	6.6%
11-15 years	Male	57.8%	24.0%	6.3%	4.8%	7.1%
	Female	64.0%	19.6%	6.2%	4.1%	6.1%
	Total	60.9%	21.8%	6.2%	4.5%	6.6%
16-20 years	Male	59.9%	18.6%	6.7%	6.8%	8.1%
	Female	64.9%	17.4%	5.5%	4.5%	7.6%
	Total	62.4%	18.0%	6.1%	5.7%	7.8%
21-25 years	Male	56.7%	17.0%	7.0%	8.7%	10.7%
	Female	61.9%	21.9%	4.9%	4.8%	6.5%
	Total	59.3%	19.5%	5.9%	6.8%	8.6%
26-30 years	Male	65.1%	17.6%	4.5%	5.7%	7.1%
	Female	66.5%	19.6%	5.2%	4.0%	4.7%
	Total	65.8%	18.5%	4.8%	4.9%	6.0%
31-35 years	Male	59.9%	18.4%	5.3%	6.6%	9.7%
	Female	67.1%	20.0%	3.6%	3.6%	5.8%
	Total	63.6%	19.2%	4.4%	5.0%	7.7%
36-40 years	Male	72.9%	12.9%	2.5%	3.4%	8.3%
	Female	69.1%	11.1%	3.9%	9.4%	6.5%
	Total	71.3%	12.2%	3.1%	5.9%	7.6%

The frequency of use of computers in mathematics, disaggregated by teachers' age, revealed slightly different patterns of use across age groups. In general, students of younger teachers reported greater use of computers than students of older teachers. However, students of teachers aged 61 to 70 reported using computers everyday or almost everyday more often than students of younger teachers. Female students reported less use of computers than male students across all age groups, although the disparity was greatest among male and female students of teachers aged 51 to 60. The frequency of computer use by teachers' age is presented in Table 4.8.

Table 4.8

Frequency of the Use of Computers in Mathematics, by Teachers' Age and Students' Gender

		Never	Rarely	Less than once a week	Once or twice a week	Everyday or almost everyday
20 - 30 years	Male	57.1%	21.3%	6.7%	6.9%	7.9%
	Female	59.3%	22.9%	6.1%	5.7%	6.1%
	Total	58.2%	22.1%	6.4%	6.3%	7.0%
31-40 years	Male	59.0%	22.0%	5.2%	7.2%	6.6%
	Female	62.1%	22.0%	5.7%	4.6%	5.7%
	Total	60.5%	22.0%	5.4%	5.9%	6.1%
41-50 years	Male	58.0%	19.5%	6.4%	6.8%	9.2%
	Female	61.4%	19.9%	6.1%	4.8%	7.8%
	Total	59.6%	19.7%	6.3%	5.8%	8.5%
51-60 years	Male	61.1%	17.9%	5.2%	6.8%	8.9%
	Female	67.1%	18.1%	4.3%	4.5%	6.1%
	Total	64.1%	18.0%	4.7%	5.7%	7.5%
61-70 years	Male	60.3%	19.1%	6.3%	2.0%	12.3%
	Female	61.5%	20.6%	5.5%	5.5%	6.9%
	Total	60.9%	19.8%	5.9%	3.7%	9.7%

When disaggregated by teachers' participation in professional development, the pattern of infrequent use of computers across students of both genders, and less frequent use among female students than male students, persisted. The greatest disparity in use by gender occurred among students of teachers trained in the use of other technology. The frequency of computer use by type of professional development is presented in Table 4.9.

Table 4.9

Frequency of the Use of Computers in Mathematics, Teachers' Professional Development and Students' Gender

		Never	Rarely	Less than once a week	Once or twice a week	Everyday or almost everyday
Basic computer skills	Male	58.2%	20.1%	5.7%	7.3%	8.7%
	Female	62.1%	20.6%	5.5%	4.9%	6.9%
	Total	60.1%	20.3%	5.6%	6.1%	7.8%
Software applications	Male	57.9%	20.8%	6.0%	7.1%	8.3%
	Female	61.8%	21.2%	5.4%	4.8%	6.8%
	Total	59.8%	21.0%	5.7%	6.0%	7.5%
Use of Internet	Male	58.0%	20.3%	5.8%	7.2%	8.7%
	Female	62.2%	20.8%	5.3%	5.0%	6.7%
	Total	60.1%	20.5%	5.6%	6.1%	7.7%
Other technology	Male	55.7%	21.9%	5.7%	7.8%	8.8%
	Female	60.3%	21.2%	5.4%	5.4%	7.7%
	Total	58.0%	21.6%	5.6%	6.6%	8.3%
Integrating technology	Male	57.8%	20.6%	5.9%	7.2%	8.4%
	Female	61.3%	21.4%	5.5%	5.0%	6.8%
	Total	59.5%	21.0%	5.7%	6.1%	7.6%
Advanced training	Male	56.6%	22.4%	6.3%	6.6%	8.1%
	Female	59.2%	22.7%	6.0%	5.4%	6.7%
	Total	57.9%	22.5%	6.2%	6.0%	7.4%

Research question two seeks to identify what relationship, if any, exists between specific applications of computers in mathematics and student achievement. An investigation of the applications of computers in the classroom found that, when asked about the use of computers for a specific purpose, the vast majority of students reported never using computers for that purpose. As shown in Table 4.10, male students reported using computers for various purposes in their mathematics class slightly more frequently than female students.

Table 4.10

Percentage of Students Reporting Use of Computers for Specific Applications, by School Urbanicity and Students' Gender

		Review math work	Solve math problems	Graph -ing	Math drills	Analyze data	Apply learning	Instruct one-on-one	Show new topics
Urban	Male	10.5%	15.9%	13.7%	14.3%	12.6%	14.5%	10.8%	11.9%
	Female	9.5%	14.2%	11.8%	12.0%	10.4%	12.6%	8.3%	11.1%
	Total	10.0%	15.0%	12.7%	13.2%	11.5%	13.6%	9.6%	11.5%
Suburb -an	Male	8.2%	13.2%	12.1%	12.2%	10.9%	13.3%	8.4%	11.2%
	Female	6.7%	12.5%	10.5%	11.3%	9.8%	12.4%	7.3%	10.0%
	Total	7.5%	12.9%	11.3%	11.7%	10.3%	12.8%	7.8%	10.6%
Rural	Male	7.1%	11.4%	10.0%	11.0%	10.4%	11.6%	8.4%	10.4%
	Female	5.5%	11.0%	9.3%	10.4%	8.3%	10.3%	6.1%	8.6%
	Total	6.3%	11.2%	9.7%	10.7%	9.4%	11.0%	7.3%	9.5%

When disaggregated by the percentage of students qualifying for FRL at the school, some interesting patterns of use emerged. As the percentage of FRL students at the school increased, so did the percentage of students reporting using computers for each application in mathematics. Interestingly, female students at schools with less than a six percent FRL population reported the use of computers at a greater rate than male students for all applications but one: the use of computers to analyze data. Similarly, female students at schools with more than a 75 percent FRL population reported the use of computers at a greater rate than male students for all applications but one: the use of computers to do math drills. Table 4.11 presents the percentage of male and female students reporting the use of computers by varying levels of school FRL populations. Graphs of these frequencies can be found in Appendix C.

Table 4.11

Percentage of Students Reporting Use of Computers in Mathematics, by School FRL and Students' Gender

		Review math work	Solve math problems	Graph -ing	Math drills	Analyze data	Apply learning	Instruct one-on-one	Show new topics
0-5%	Male	5.0%	10.2%	10.9%	9.8%	9.7%	11.0%	6.0%	10.4%
	Female	5.1%	12.5%	12.0%	11.1%	9.0%	12.6%	6.9%	12.2%
	Total	5.1%	11.4%	11.4%	10.4%	9.4%	11.8%	6.5%	11.3%
6-10%	Male	7.7%	14.5%	12.7%	13.6%	11.9%	14.4%	9.8%	12.4%
	Female	5.9%	12.9%	9.6%	10.0%	8.1%	11.5%	5.1%	10.7%
	Total	6.7%	13.7%	11.1%	11.7%	9.9%	12.9%	7.3%	11.5%
11-20%	Male	6.8%	11.8%	11.2%	11.1%	10.7%	11.6%	8.1%	9.4%
	Female	6.0%	12.4%	9.8%	11.5%	9.4%	11.8%	7.0%	8.4%
	Total	6.4%	12.1%	10.5%	11.3%	10.1%	11.7%	7.5%	8.9%
21-30%	Male	8.7%	13.6%	12.0%	12.6%	10.0%	12.9%	9.6%	11.0%
	Female	5.1%	9.4%	7.7%	8.0%	7.6%	9.4%	5.0%	6.1%
	Total	6.9%	11.6%	9.9%	10.3%	8.9%	11.2%	7.4%	8.6%
31-50%	Male	10.8%	15.8%	12.5%	14.6%	12.1%	14.7%	9.9%	11.2%
	Female	7.7%	12.1%	9.6%	11.0%	8.4%	10.8%	7.3%	10.3%
	Total	9.3%	14.0%	11.1%	12.9%	10.3%	12.8%	8.6%	10.8%
51-75%	Male	16.3%	17.1%	16.7%	17.2%	15.8%	17.9%	13.5%	15.8%
	Female	14.8%	16.9%	14.1%	17.0%	13.9%	14.4%	11.2%	11.5%
	Total	15.6%	17.0%	15.4%	17.1%	14.9%	16.2%	12.4%	13.7%
76-100%	Male	16.4%	20.5%	14.3%	18.1%	15.2%	18.0%	15.1%	14.3%
	Female	19.2%	23.2%	17.7%	17.4%	19.1%	22.1%	17.7%	15.9%
	Total	17.9%	21.9%	16.1%	17.7%	17.3%	20.2%	16.5%	15.1%

As shown in Table 4.12, students at public schools reported greater use of computers than students at Catholic or non-Catholic private schools. Female students at public schools reported less use of computers for all applications than male students. However, female students at Catholic schools reported greater use of computers for all applications than male students. Similarly, female students at non-Catholic private schools reported greater use of computers than male students for all applications but one: reviewing math work.

Table 4.12

Percentage of Students Reporting Use of Computers for Specific Applications, by School Type and Students' Gender

		Review math work	Solve math problems	Graph -ing	Math drills	Analyze data	Apply learn-ing	Instruct one-on-one	Show new topics
Public	Male	9.0%	14.1%	12.5%	13.1%	11.7%	13.7%	9.5%	11.6%
	Female	7.6%	13.0%	10.6%	11.6%	9.8%	12.1%	7.6%	10.1%
	Total	8.3%	13.6%	11.6%	12.3%	10.8%	12.9%	8.5%	10.8%
Catholic	Male	4.2%	7.4%	7.7%	7.2%	5.8%	9.6%	4.7%	7.2%
	Female	4.7%	9.6%	10.7%	9.0%	7.9%	11.5%	4.8%	9.0%
	Total	4.4%	8.4%	9.1%	8.1%	6.8%	10.5%	4.8%	8.1%
Non-Catholic private	Male	4.3%	7.7%	8.0%	6.3%	7.1%	8.5%	4.5%	7.4%
	Female	3.5%	9.4%	11.0%	7.2%	8.2%	9.9%	5.0%	9.8%
	Total	3.9%	8.5%	9.5%	6.7%	7.7%	9.2%	4.7%	8.6%

Table 4.13 presents the responses of male and female students' teachers when asked about their exposure to training in technology within the last three years. Less than half of teachers reported receiving training in the use of other technology, and less than half of teachers reported receiving follow-up or advanced training. The dichotomous nature of these variables prevents a thorough analysis of the quantity or quality of the professional development received by teachers. However, the low percentage of teachers reporting that they received follow-up or advanced training may serve as an indication that few teachers

received professional development of sufficient duration and depth to fully implement technology in the classroom.

Table 4.13

Frequency of Mathematics Teachers' Participation in Professional Development, by Students' Gender

	Female		Male	
	No	Yes	No	Yes
Received training in basic computer skills	18.3%	81.7%	17.6%	82.4%
Received training in software applications	16.4%	83.6%	16.4%	83.6%
Received training in use of Internet	18.8%	81.2%	18.8%	81.2%
Received training in use of other technology	57.9%	42.1%	56.8%	43.2%
Received training in integrating technology	22.5%	77.5%	21.4%	78.6%
Received follow-up or advanced training	54.3%	45.7%	52.3%	47.7%

However, as depicted in Table 4.14, teachers' exposure to professional development on the use of technology appears to have little influence on the use of computers for application in the classroom. Students of teachers who participated in professional development reported the use of computers for each application at a higher rate than students of teachers who did not participate in professional development, but minimally so.

Table 4.14

Percentage of Students Reporting Use of Computers for Specific Applications, by Teachers' Professional Development

		Review math work	Solve math problems	Graph -ing	Math drills	Analyze data	Apply learn- ing	Instruct one- on-one	Show new topics
Basic comp. skills	No	6.7%	11.5%	9.5%	10.9%	9.4%	11.2%	7.1%	9.7%
	Yes	8.1%	13.3%	11.9%	12.0%	10.7%	13.0%	8.5%	11.0%
Software applications	No	7.4%	10.4%	9.3%	10.1%	8.6%	10.2%	6.8%	8.9%
	Yes	7.9%	13.4%	11.9%	12.1%	10.8%	13.1%	8.5%	11.1%
Use of Internet	No	7.6%	12.4%	10.9%	11.3%	10.3%	11.1%	7.7%	9.7%
	Yes	7.9%	13.0%	11.6%	11.9%	10.5%	13.0%	8.3%	11.0%
Use of other technology	No	7.5%	12.7%	10.8%	11.4%	10.3%	12.2%	7.6%	9.7%
	Yes	8.3%	13.3%	12.4%	12.4%	10.6%	13.2%	9.1%	12.1%
Integrating technology	No	7.4%	10.1%	9.5%	10.1%	8.9%	10.5%	6.8%	8.9%
	Yes	8.0%	13.8%	12.0%	12.3%	10.9%	13.3%	8.7%	11.3%
Advanced training	No	7.3%	11.9%	10.0%	10.8%	9.3%	11.2%	7.1%	9.8%
	Yes	8.4%	14.2%	13.1%	12.9%	11.7%	14.3%	9.5%	11.8%

Missing Analysis

Several of the independent variables of interest in the study had missing data, as shown in Table 4.15. Data that are not missing at random present a challenge to analysis, and there are no strict guidelines regarding the best way to handle missing values. Both ignoring the missing data and imputing the data may affect the results of the analysis. In the case of multivariate analysis, imputation can distort coefficients of association and correlation relating variables. It is relatively common to drop cases with missing values when the sample size is large and the number of cases with missing data is small (typically less than 5%; Tabachnick & Fidell, 2007). However, as shown in Table 4.15, the percentage of cases with missing data was greater than 5%.

Table 4.15

Missingness of Independent Variables

	Valid		Missing	
	N	Percent	N	Percent
Frequency of computer use	14,087	92.1%	1,208	7.9%
Review math work	13,721	89.7%	1,574	10.3%
Solve math problems	13,992	91.5%	1,303	8.5%
Graphing	13,682	89.5%	1,613	10.5%
Math drills	13,925	91.0%	1,370	9.0%
Analyze data	13,657	89.3%	1,638	10.7%
Apply learning	13,902	90.9%	1,393	9.1%
Instruct one-on-one	13,699	89.6%	1,596	10.4%
Show new topics	13,925	91.0%	1,370	9.0%
Home computer use	14,271	93.3%	1,024	6.7%
Teacher’s age	12,848	84.0%	2,447	16.0%
Teacher’s years of experience	12,793	83.6%	2,502	16.4%
Training in basic computer skills	12,833	83.9%	2,462	16.1%
Training in software applications	12,813	83.8%	2,482	16.2%
Training in use of Internet	12,795	83.7%	2,500	16.3%
Training in other technology	12,804	83.7%	2,491	16.3%
Training in integrating technology	12,848	84.0%	2,447	16.0%
Advanced training	12,727	83.2%	2,568	16.8%

Missing data was analyzed using PASW (SPSS) 18 to determine if the data were missing completely at random (MCAR), missing at random (MAR), or not missing at random. Little’s MCAR test indicated that the data were not MCAR, and Separate Variance t-tests indicated that the data were not MAR. Based on this analysis, the decision was made to impute missing data using fully conditional multiple imputation in PASW (SPSS) 18. Multiple imputation works by replicating the dataset into several copies. Each copy of the dataset is imputed separately using a random sample of the cases with complete responses

(Tabachnick & Fidell, 2007). PASW (SPSS) 18 uses the Markov chain Monte Carlo (MCMC) method to impute data. Each imputed dataset is analyzed separately, and the results are pooled.

To be as thorough and as accurate in the analysis as possible, the dataset was analyzed twice: one approach allowed cases with missing values to be listwise deleted from analysis; the other approach calculated the pooled results of each imputed dataset. The number of imputations typically employed to sufficiently model missing values ranges from three to five (Rubin, 1996). Five imputations were calculated for this study. Non-imputed results are reported in the following sections. Results of the MLM analysis of the imputed dataset can be found in Appendix D.

Logistic Regression

This study investigates the relationship between teachers' participation in professional development as it relates to student achievement. Also of interest is the relationship between teachers' participation in professional development and the use of computers in the classroom. Binary logistic regression was used to determine whether students of teachers who had participated in professional development had a greater likelihood of reporting computer use in their mathematics class. As presented in Table 4.16, students of teachers who had participated in various measures professional development were more likely to report using computers in the classroom than students of teachers who had not participated in professional development on all measures.

Table 4.16

Odds of Students Reporting the Use of Computers in Mathematics, by Teachers' Professional Development

	Odds Ratio	p-value
Training in basic computer skills	1.16	<.001
Training in software applications	1.30	<.001
Training in use of Internet	1.17	<.001
Training in other technology	1.22	<.001
Training in integrating technology	1.27	<.001
Advanced training	1.25	<.001

Binary logistic regression was also used to investigate the relationship between teachers' professional development and the use of computers for specific applications in the classroom. As depicted in Table 4.17, teachers' participation in all measures of professional development is related to greater odds of use across each application of computers. In general, teachers' participation in software application, integrating technology, and advanced training generated the greatest odds of use on all computer applications but one, review math work. Teachers' participation in basic computer skills training generated the greatest odds of using computers to review math work. Training on the use of the Internet generated the lowest odds of use on all applications but apply learning.

Table 4.17

Odds of Students Reporting the Use of Computers for Specific Applications, by Teachers' Professional Development

	Review math work	Solve math problems	Graph-ing	Math drills	Analyze data	Apply learning	Instruct one-on-one	Show new topics
Basic computer skills	1.24*	1.17*	1.28*	1.12*	1.15*	1.19*	1.22*	1.15*
Software applications	1.08*	1.33*	1.31*	1.23*	1.28*	1.33*	1.27*	1.27*
Use of Internet	1.04*	1.06*	1.07*	1.07*	1.01*	1.20*	1.08*	1.14*
Use of other technology	1.11*	1.06*	1.16*	1.10*	1.03*	1.01*	1.20*	1.28*
Integrating technology	1.09*	1.43*	1.30*	1.25*	1.26*	1.32*	1.29*	1.30*
Advanced training	1.16*	1.23*	1.35*	1.22*	1.29*	1.32*	1.36*	1.23*

* $p < .001$

Multilevel Model Analysis

To fully address the research questions guiding this study, differences in students' standardized mathematics score were analyzed using multilevel modeling procedures (Raudenbush, Bryk, & Congdon, 2004). Multilevel modeling (MLM) analyses were employed to evaluate student achievement in mathematics to investigate the within- and between-school variability in nested data (students within schools), to manage unbalanced data, as each school has different sample sizes of students, and to appropriately investigate both student and school-level variables (Raudenbush & Bryk, 2002).

The null (or fully-unconditional) model was evaluated first to ensure that there was sufficient variability at both level 1 (student-level) and level 2 (school-level) to warrant further analyses. The following equation represents the null model, in which no predictors are present:

Level 1: Math Standardized Scale Score = $\beta_{0j} + r_{ij}$

Level 2: $\beta_{0i} = \gamma_{00} + u_{0i}$

Where β_0 is the level 1 intercept, r is the residual error at level 1, and u is the random error at level 2. In this model, γ_{00} is the point estimate for the grand mean of the factor, at school *i* and student *j*; r_{ij} represents the residual within-school variance in the factor, and u_{0i} represents the between-school variability in the factor. Results of the analysis indicate that 22.49% of the variability in students' standardized math score was between schools ($\tau_{00} = 21.13$) and 77.51% was within schools ($\sigma^2 = 72.83$). That is, there is variance within schools, and school-level factors explain some of the differences in student achievement. The variation between schools was sufficient for further analysis.

Next, the non-randomly varying slopes model (full model) was compared with the null model. The full model addresses all three research questions with the inclusion of all key independent variables, including frequency of computer use (BYS29H), review math work (BYS31A), solve math problems (BYS31B), graphing (BYS31C), math drills (BYS31D), analyze data (BYS31E), apply learning (BYS31F), instruct one-on-one (BYS31G), show new topics (BYS31H), training in basic computer skills (BYTM38A), training in software applications (BYTM38B), training in use of the Internet (BYTM38C), training in other technology (BYTM38D), training in integrating technology (BYTM38E), and advanced training (BYTM38F). The model also investigates the interaction between gender and home computer use (BYS47A), gender and frequency of computer use at school, and gender and students' teachers' exposure to professional development in technology.

The model was run twice—once with no school level (level 2) predictors and once with all predictors. It was important to exclude the school level predictors to allow a comparison of student achievement with and without the controls at the school level. The full model includes all level 1 variables, and also controls for school level variables: (a) the urbanicity of the school (BYURBAN), (b) the type of school (BYSCTRL), and (c) the percentage of students in the 10th grade at the school that receive free lunch (BY10FLP). The equation for the full model is represented by:

Level 1: Math Standardized Scale Score = β_{0ij} + β_{1j}(Female) + β_{2j}(AmIndian) + β_{3j}(Asian) + β_{4j}(Black) + β_{5j}(Hispanic) + β_{6j}(Multiracial) + β_{7j}(SES) + β_{8j}(Frequency of Computer Use) + β_{9j}(Review Math Work) + β_{10j}(Solve Math Problems) + β_{11j}(Graphing) + β_{12j}(Math Drills) + β_{13j}(Analyze Data) + β_{14j}(Apply Learning) + β_{15j}(Instruct One-on-One) + β_{16j}(Show New Topics) + β_{17j}(Home Computer Use) + β_{18j}(Training in Basic Computer Skills) + β_{19j}(Training in Software Applications) + β_{20j}(Training in use of Internet) + β_{21j}(Training in Other Technology) + β_{22j}(Training in Integrating Technology) + β_{23j}(Advanced Training) + β_{24j}(Female*Frequency of Computer Use) + β_{25j}(Female*Review Math Work) + β_{26j}(Female*Solve Math Problems) + β_{27j}(Female*Graphing) + β_{28j}(Female*Math Drills) + β_{29j}(Female*Analyze Data) + β_{30j}(Female*Apply Learning) + β_{31j}(Female*Instruct One-on-One) +

β_{32j}(Female*Show New Topics) + β_{33j}(Female*Home Computer Use) + β_{34j}(Female*Training in Basic Computer Skills) + β_{35j}(Female*Training in Software Applications) + β_{36j}(Female*Training in use of Internet) + β_{37j}(Female*Training in Other Technology) + β_{38j}(Female*Training in Integrating Technology) + β_{39j}*(Female*Advanced Training) + r_{ij}

Level 2: $\beta_{0j} = \gamma_{00} + \gamma_{01}$(Urban) + γ_{02}(Rural) + γ_{03}(Catholic) +γ_{04}(NonCatholicPrivate) + γ_{05}(FRL0to5) + γ_{06}(FRL6to10) + γ_{07}(FRL11to20) + γ_{08}(FRL21to30) + γ_{09}(FRL51to75) + γ_{010}(FRL76to100) + u_{0j}

$\beta_{qj} = \gamma_{q0}$ for each q =1 to 39

In this model, γ_{00} is the grand mean of students' mathematics standardized test scores when all predictors equal zero, at school *j* and student *i*; r_{ij} represents the residual within-school variance in students' mathematics scores; and u_{0i} represents the between-school variability in students' mathematics scores, which is associated with the τ_{00} statistic, after accounting for the effects of the predictors. The full model includes additional γ_{010} components, which represent the between-school differences in students' mathematics scores as a function of the respective level 2 predictor, after accounting for the other level 2 variables.

Analysis of the weighted and non-imputed data using a non-randomly varying slopes model revealed several significant predictors, as shown in Table 4.18. In the level 1 only model, level 1 variables accounted for 20.41% of the within-school variability in students' standardized mathematics scores. In the full (levels 1 and 2) model, level 1 variables accounted for 20.57% of the within-school variability, and level 2 variables accounted for 68.99% of between-school variability in students' standardized mathematics scores. To thoroughly investigate any variation that may be attributed to weighting or imputation, the model was run three additional times: with imputed and weighted data, with imputed and unweighted data, and with non-imputed and unweighted data. Findings from these analyses are presented in Appendices D, E, and F, and a comparison of each model is presented in Appendix G.

Table 4.18

MLM Models of Mathematics Achievement

	Level 1	Level 1 & Level 2
Level 1		
Standardized math score	51.47***	50.40***
Computer use		
Frequency of computer use	-1.25***	-1.22***
Review math work	-4.60***	-4.46***
Solve math problems	-0.83	-0.81
Graphing	0.52	0.28
Math drills	-1.25	-1.26
Analyze data	0.87	0.83
Apply learning	2.76**	2.81**
Instruct one-on-one	1.36	1.34
Show new topics	-0.01	0.10
Home computer use	1.33***	1.33***
Professional development		
Training in basic computer skills	-0.33	-0.26
Training in software applications	1.03	0.93
Training in use of Internet	0.21	0.45
Training in other technology	-0.45	-0.54
Training in integrating technology	0.05	0.07
Advanced training	-0.21	-0.15
Student demographics		
American Indian	-3.25***	-2.87**
Asian	2.24**	2.33**
Black	-5.05***	-4.38***
Hispanic	-3.95***	-3.50***
Multiracial	-1.26*	-1.17*
Female	-0.18	-0.12
Socio-economic status	3.40***	3.18***
Teacher demographics		
Teacher’s years of experience	0.12***	0.12***
Teacher’s age	-0.04	-0.04

Table 4.18 (continued)

	Level 1	Level 1 & Level 2
Gender interactions		
Female * Frequency of computer use	0.14	0.12
Female * Review math work	0.65	0.77
Female * Solve math problems	0.15	0.23
Female * Graphing	2.06	2.16
Female * Math drills	0.10	-0.02
Female * Analyze data	-2.09	-2.07
Female * Apply Learning	-0.31	-0.30
Female * Instruct one-on-one	-2.81*	-2.73*
Female * Show new topics	1.82	1.64
Female * Training in basic computer skills	0.11	0.15
Female * Training in software applications	-1.28	-1.26
Female * Training in use of Internet	1.24	1.15
Female * Training in other technology	0.29	0.25
Female * Training in integrating technology	0.34	0.38
Female * Advanced training	0.57	0.62
Female * Home computer use	-0.64**	-0.66**
Level 2		
Catholic		0.79
Non-Catholic private		0.44
Urban		-0.36
Rural		0.20
FRL 0 to 5		1.87**
FRL 6 to 10		1.61
FRL 11 to 20		1.12
FRL 21 to 30		-0.31
FRL 51 to 75		-1.08
FRL 76 to 100		-2.24**
Random effects	Variance component	
Intercept (variance between schools)	57.97	57.85
Level 1 (variance within schools)	7.60	6.55
Intraclass Correlation	.12	.10
Variance in achievement between schools (%) explained		69.00
Variance in achievement within schools (%) explained	20.41	20.57

* $p < .05$; ** $p < .01$; *** $p < .001$

Both models identified the frequency of computer use, the use of computers to review math work in mathematics, the use of computers to apply learning in mathematics, home computer use, the interaction between gender and mathematics teachers' use of computers to instruct one-on-one, and the interaction between gender and home computer use as significant predictors of student achievement in mathematics. The addition of level 2 variables did not affect the significance of these predictors, and only changed the coefficients by a trivial amount. The discussion of how these findings inform the research questions guiding the study will refer to the values calculated from the full (level 1 and level 2) model.

Research Question 1

What is the relationship between the frequency of use of computer technology in mathematics classes and student achievement in mathematics? Do these relationships vary by the gender of the student?

The frequency with which computers are used in the classroom was negatively related to students' standardized mathematics scores (γ_{80} = -1.22, t = -7.66, p < .001). As discussed earlier, the frequency with which students reported using computers in their mathematics classes was low, with 61% of students reporting that they never used computers in their most recent mathematics class. MLM indicates that the use of computers in mathematics is associated with a reduction in student achievement.

The interaction between gender and the use of computers in the classroom was not significant. However, male students reported a greater frequency of use than female students, with 41.4% of male students indicating that they used computers at least "rarely," compared to 37.3% of female students.

While it is not directly related to research question one, the frequency with which students use computers at home was found to be significantly positively related to students' standardized mathematics scores ($\gamma_{170} = 1.33$, $t = 6.37$, $p < .001$). The coefficient of this predictor is nearly as large as the coefficient of the frequency of computer use in the classroom, indicating that the use of computers in the home is as strong a predictor of student achievement as the use of computers in the classroom.

The interaction between gender and the use of computers at home was found to be significant, as well ($\gamma_{330} = -0.66$, $t = -2.76$, $p =.006$). As depicted in Figure 4.1, the interaction was such that male students who indicated that they used a home computer frequently had higher standardized mathematics scores than female students who indicated that they used a home computer frequently.

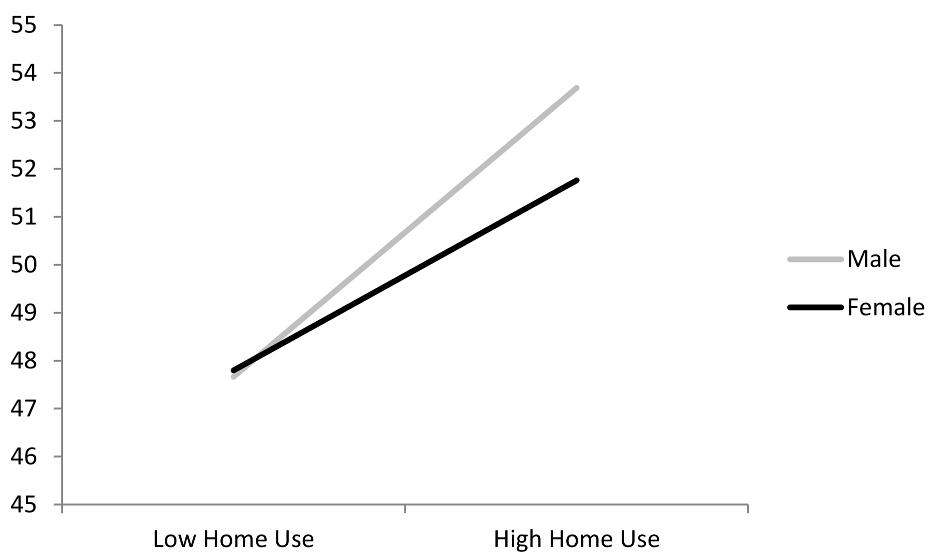

Figure 4.1. Standardized math scores of students by frequency of use of computers at home, by gender

Research Question 2

What are the relationships between specific uses of computer technology in mathematics classrooms and student achievement in mathematics? Do these relationships vary by the gender of the student?

Of the eight variables related to the applications of computers in the classroom, two were identified as significant predictors of student performance. The use of computers to review math work was negatively related to student achievement ($\gamma_{90} = -4.46$, $t = -3.86$, $p < .001$), and the use of computers to apply learning was positively related to student achievement ($\gamma_{140} = 2.81$, $t = 3.04$, $p = .003$). However, the interactions between gender and these variables were not significant. A significant interaction was identified between gender and mathematics teachers' use of the computer to instruct one-on-one ($\gamma_{310} = -2.73$, $t = -2.11$, $p = .035$). As shown in Figure 4.2, the interaction was such that male students of teachers who did not use computers to instruct one-on-one had higher math scores than both female students and male and female students of teachers who used computers to instruct one-on-one.

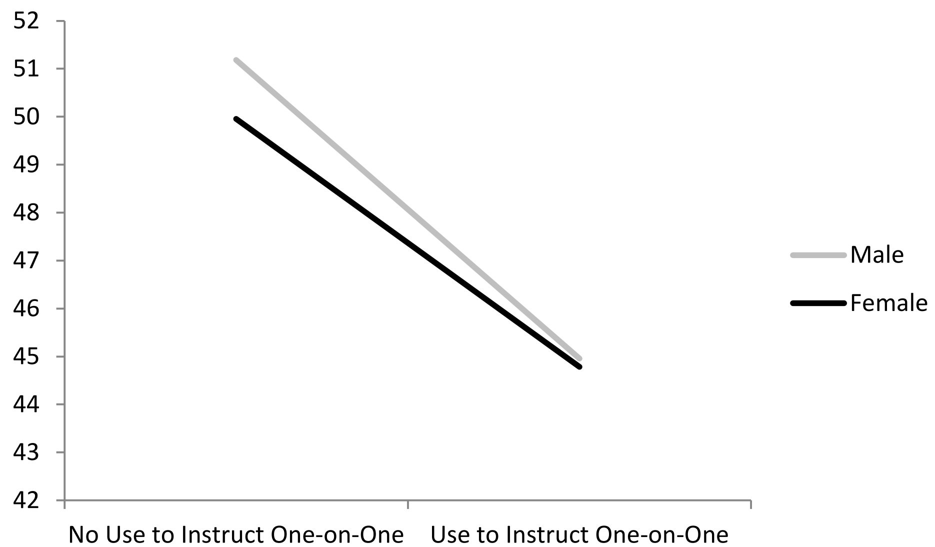

Figure 4.2. Standardized math scores of students whose teachers used (or did not use) computers to instruct one-on-one, by gender

Research Question 3

What is the relationship between mathematics teachers' professional development in technology and student achievement in mathematics? Does this relationship differ by the gender of the student?

Analysis of the variables measuring teachers' exposure to professional development in technology revealed no significant differences between the mathematics performance of students whose teachers reported receiving professional development and students whose teachers did not report receiving professional development. The interactions between gender and the measures of teachers' exposure to professional development were not statistically significant, as well.

Chapter Summary

This chapter began with an analysis of the normality of the predictors. Because a large majority of students reported never using computers in the classroom, the variables measuring the application of computers in the classroom exceeded acceptable values of skewness and kurtosis, indicators of normality. As a result, these variables were transformed into dichotomous variables. Descriptive analysis found that the use of computers in the classroom varied slightly across schools, with more frequent use at public schools and schools with a greater percentage of FRL students. Male students reported using computers in the classroom more frequently than female students. The use of computers varied little among teachers who received professional development in the use of computers and teachers who did not.

Multilevel modeling was employed to fully explore the three research questions guiding the study. The use of computers to review math work was found to be negatively related to achievement, and the use of computers to apply learning was positively related to achievement. The interaction between gender and the use of computers to instruct one-on-one was significant. No significant relationships were identified between mathematics teachers' exposure to professional development and student achievement in mathematics. A summary of the analysis and results presented in this chapter is depicted in Table 4.19.

The following chapter will discuss the implications of these findings, as well as the limitations of this study and the need for future research.

Table 4.19

Explanation of Procedures and Results

Procedure	Reason	Results
Testing assumptions (histograms, skew, and kurtosis)	To determine the normality of the distribution of non-dichotomous variables	All variables were within acceptable limits of skew and kurtosis except for measures of the frequency of use of computers for specific applications. These variables were dichotomized; an alternate model in which these variables were dummy-coded by frequency of use was reported in Appendix H.
Collinearity diagnostics	To determine the degree to which variables were associated with each other	All variables were below the threshold of concern for multicollinearity except for a few measures of the use of computers for specific applications. These variables remained as separate measures in the primary model; a composite of these variables was calculated for a model reported in Appendix I.
Descriptive statistics (means and frequencies)	To determine patterns among variables; particularly disparate patterns among male and female students	Male students reported greater use of computers than female students in virtually every disaggregation. Students at public schools reported greater use of computers than students at Catholic and non-Catholic private schools. Rural students reported less use than urban and suburban students. Students at schools with greater FRL populations reported more use than students at schools with lower FRL populations. Students of teachers who had participated in professional development reported slightly greater use of computers than students of teachers who had not participated in professional development.
Missing analysis	To determine the pattern of missing data and to develop the best strategy for dealing with missing data	Between 6 and 11 percent of responses to the student questionnaire were missing, and about 16 percent of responses to the teacher questionnaire were missing. The decision was made to run the model twice: once with missing cases listwise deleted (reported in Chapter 4) and once with missing cases imputed via multiple imputation (reported in Appendix D).

Table 4.19 (continued)

Procedure	Reason	Results
Logistic regression	To determine the relationship between teachers' participation in professional development and students' use of computers in the classroom	Students of teachers who participated in professional development were more likely to use computers in the classroom than students of teachers who did not participate in professional development. Students of teachers who participated in training in software applications, integrating technology, and advanced training had the greatest odds of using computers in the classroom compared to students of teachers who did not participate in these trainings.
Multilevel model analysis (MLM)	To determine the relationship between the use of computers in the classroom and student achievement while controlling for demographic variables and accounting for the contextual effects of the school	The use of computers in the classroom was negatively related to student achievement. Specifically, the use of computers to review math work was negatively related to student achievement, and the use of computers to apply learning was positively related to student achievement. Teachers' participation in professional development was not related to student achievement. There were interaction effects between gender and the use of computers to instruct one-on-one such that male and female students who participated in one-on-one instruction had roughly equivalent test scores, and gender and the use of computers at home such that male students who used computers at home often had higher test scores than female students who used computers at home often.

Chapter 5

Discussion

Introduction

Chapter 5 presents a summary of the key findings. The limitations of the study are shared, with particular attention paid to limitations that may have affected the outcome of the analysis. The chapter then presents a discussion of the need for future research on the role of computer technology in the classroom.

Key Findings

The analysis discussed in Chapter 4 identified low use of computers in mathematics instruction. Over half of all students reported never using a computer in their most recent mathematics class. The frequency with which students reported using computers for specific applications in their mathematics classes was even lower, with over 80 percent of students reporting never using computers for each application.

The use of computers in mathematics was associated with lower standardized scores on the mathematics test. The investigation of the relationship between specific applications of computers in the classroom and student achievement found a positive relationship between the use of computers to apply learning and achievement, and a negative relationship between the use of computers to review math work and achievement. A significant interaction between gender and the use of computers to instruct one-on-one was identified. Male students of teachers who did not use computers to instruct one-on-one had higher math scores than female students whose teachers did not use computers to instruct one-on-one. However, male and female students of teachers who did use computers to instruct one-on-one had comparable scores on the mathematics test.

The analysis found that the measures of teachers' professional development were not significant predictors of student achievement. Logistic regression indicated that students of teachers who reported participating in professional development reported greater use of computers in the classroom than students of teachers who did not participate in professional development, reflecting a relationship between teachers' professional development in technology and computer use in the classroom.

Implications

The Use of Computers in Instruction

The infrequent use of computers in the classroom identified in this study is consistent with the existing literature (Bain, 2004; Cavanaugh et al., 2007; Cuban, 2001; Cuban et al., 2001; Ross & Strahl, 2005; Shapely et al, 2010; Windschitl & Sahl, 2002). Technology use has been found to be particularly low in mathematics, where teachers often find it more difficult to integrate computers into instruction than other subjects, such as English/language arts (Barron et al., 2003; Bebell & Kay, 2010; Becker, 2001; Corn et al, 2011; Cuban et al., 2001; Grimes & Warschauer, 2008; Sclater et al., 2006).

Research suggests that, in many cases, technology is primarily utilized in manners that support teachers' existing patterns of instruction (Cuban et al., 2001; Lei & Zhao, 2007; Windschitl & Sahl, 2002). Teachers of mathematics may find it particularly difficult to incorporate the use of computers into instruction because computers do not complement pre-existing lesson plans. Aside from asking students to take notes on individual laptops rather than on paper, teachers may find that they have to alter their instructional strategy to utilize computers in their lessons.

The frequency with which students at lower socioeconomic status schools (schools with a high percentage of FRL students) used computers was slightly greater than the frequency with which students at higher socioeconomic status schools used computers. This confirms previous research that found that students of low socioeconomic status tend to be exposed to more frequent use of technology than students of high socioeconomic status (Becker, 2001; Warschauer et al., 2004; Wenglinsky, 1998). Interestingly, these findings contradict Weaver's (2000) analysis of the NELS:88 dataset, in which she identified a more frequent use of technology among students of higher socioeconomic status than among students of lower socioeconomic status. This study, in conjunction with more recent research into the frequency of use of technology in instruction, suggests that the use of technology in schools is no longer reserved for students of higher socioeconomic status (Thomas, 2008; Warschauer, 2010). However, as evidenced by this study and others (e.g., Bebell & Kay, 2010; Dunleavy & Heinecke, 2008; O'Dwyer et al., 2008), greater use of technology is not necessarily positive in terms of student achievement. Future analysis of computer use in instruction may focus more on the quality rather than the quantity of the instruction provided with the assistance of computers.

A smaller percentage of students with highly experienced teachers reported the use of computers in the classroom than students with less experienced teachers. Students of teachers with less than ten years of experience reported the greatest use of computers in the classroom, and students of teachers with over 35 years of experience reported the least use of computers in the classroom. Similarly, students of younger teachers reported greater use of computers than students of older teachers. This finding confirms research that suggests that younger teachers generally feel more comfortable with technology and are able to find methods of application in the classroom more readily than older, or more experienced, teachers (Mollette et al., 2010; Russell et al., 2003). It is also possible that older, or more experienced, teachers have perfected their lesson plans and are less willing to change or adapt those plans to incorporate the use of technology. However, students of teachers aged 61 to 70 reported using computers "everyday or almost everyday" more often than students of younger teachers. This finding contradicts the explanations of the variance in technology use across teachers' age and may necessitate further investigation.

Computer Use and Mathematics Achievement

One of the primary findings of this study was the significant, negative relationship between the frequency of use of computers in mathematics and student achievement in mathematics. This finding indicates that the use of computers in mathematics is associated with a reduction in student achievement. The existing research into the relationship between computer use in the classroom and mathematics achievement has identified positive, negative, and non-existent relationships (Campuzano et al., 2009; Hunter & Greever-Rice, 2007; Lowther et al., 2003; Mollette et al., 2010; Richtel, 2011; Shapely et al., 2009; Shapely et al., 2010). This finding adds to the body of research that reports a negative association between technology use and student achievement in mathematics.

It is a compelling finding that, after controlling for students' race/ethnicity and gender, teachers' age, years of experience, and professional development opportunities, the urbanicity of the school, the type of school (public, Catholic, or non-Catholic private), and the socioeconomic status of both the student and the school, there is a significant negative relationship between the use of computers in mathematics and student achievement in mathematics. The strength of the relationship was such that, with each incremental increase in the frequency of computer use, students' standardized mathematics scores decreased by more than one point. The presence of the control variables makes it difficult to dismiss this finding.

Several studies suggest that the use of technology has a variable relationship with student achievement in mathematics, depending on the manner in which technology is used (Bebell & Kay, 2010; Cuban et al., 2001; Dynarski et al., 2007; Isiksal & Aksar, 2005; Lei & Zhao, 2007; Pierce, 2007; Tienken & Maher, 2007). Taken alone, without further inspection, the negative relationship between the frequency of computer use in mathematics and student achievement in mathematics might suggest that all applications of computers in the classroom are associated with negative student outcomes in mathematics. However, when investigating the specific applications of computers in the classroom, only two applications of computer use were identified as significant predictors of student achievement: the use of computers to review math work and the use of computers to apply learning.

The use of computers to review math work was negatively related to student achievement in mathematics. Research suggests that technology is used primary to reinforce pre-existing methods of instruction in the classroom. Cuban et al. (2001) labeled the manner in which technology was used in the classroom as "uninspired." As discussed earlier, research suggests that mathematics teachers have a particularly difficult time finding ways to incorporate technology into instruction, particularly in ways that do not simply serve to support existing lesson plans. This negative relationship reflects Wenglinksky's (1998) finding of a negative relationship between the use of computers for "lower-order" tasks, such as drill and practice, and student achievement. This finding suggests that the use of computers to review math work may be neither engaging nor challenging. In fact, the use of computers to review math work appears to be a lower-order task that may detrimental to student achievement in mathematics.

On the other hand, the use of technology to apply learning was positively related to student achievement. Although the study is limited in that the description of this application is open to interpretation, the use of computers in this manner may serve as a "higher-order" task that engages and challenges students. This finding also confirms research that suggests that positive relationships between the use of technology and student achievement is possible when technology is used in a thoughtful and constructive manner (Bebell & Kay, 2010; Dynarski et al., 2007; Isiksal & Aksar, 2005; Lei & Zhao, 2007; Wenglinsky, 1998).

Home Computer Use

Although the use of computers in the home was not explicitly addressed in the research questions, an interesting finding of this study was the significant, positive relationship between the use of a home computer and student achievement. This finding reflects previous research that identified a positive relationship between students' use of a home computer and student achievement (Attewell & Battle, 1999; Bebell & Kay, 2010; Fairlie, 2005; Shapley et al., 2010; Wenglinsky, 1998). This is a meaningful relationship, especially with the presence of students' socioeconomic status serving as a control in the model. Even when controlling for socioeconomic status and other student and school-level factors, students' use of a home computer was associated with higher standardized scores on the mathematics test. It is possible that students using computers more frequently have a support system in the home that enables them to both use and navigate a home computer. This relationship should be more fully explored, as the positive relationship between home computer use and student achievement could inform best practice when computers are deployed in the classroom.

Computer Use, Math Achievement, and Gender

Of particular interest for this study was the role that gender played in the relationship between technology use in the classroom and student achievement in mathematics. Female students generally reported less frequent use of computers in mathematics than male students. Interestingly, female students at private (Catholic and non-Catholic private) schools reported slightly greater average use of computers than male students. This was true in general and across all applications but one (the use of computers to review math work at non-Catholic private schools). It is unclear why this trend occurred at private schools. It is possible that these schools had smaller class sizes, allowing teachers time to facilitate the use of computers in the classroom.

Another interesting finding was the frequency of use of technology across schools with different FRL populations. Among the schools with the most and least needy population, female students reported slightly greater use of computers in the classroom than male students. This finding at the lowest end of the FRL spectrum may be representative of computer use at private schools. However, the greater use among female students at schools with the largest FRL population, while slight, was unusual.

This study also identified some interesting interactions between gender, computer use, and achievement. A significant interaction was identified between gender and mathematics teachers' use of the computer to instruct one-on-one. The interaction was such that male students whose teachers never used computers to instruct one-on-one had higher standardized scores in mathematics than females, but male and female students whose teachers did use computers to instruct one-on-one had roughly equivalent mathematics scores. The scores of students whose teachers used computers to instruct one-on-one were lower than the scores of students whose teachers did not use computers to instruct one-on-one. There are two possible explanations for this finding:

1) The use of computers to instruct one-on-one is negatively related to student achievement, particularly for male students.
2) Students of teachers using computers to instruct one-on-one may be struggling and attempting to catch up with the rest of the class. The use of computers to instruct one-on-one may serve as a tool for teachers to help students master material. This possibility suggests that the use of computers to instruct one-on-one is more beneficial for female students than for male students, resulting in roughly equal test scores for students of both genders.

The second possibility is more likely, given that the relationship between one-on-one instruction and achievement, while not significant, was positive, indicating that the use of one-on-one instruction is associated with higher test scores. This relationship calls for further research, as this finding could be an important application of the use of computers to close the gender gap in mathematics.

A significant interaction was also identified between gender and the use of computers at home such that male and female students had roughly equivalent scores at each measure of frequency except for “everyday or almost everyday.” Male students who reported that they used computers “everyday or almost everyday” had higher standardized scores on the mathematics test than female students. This indicates that male students derive greater benefit, in terms of mathematics achievement, from the daily use of computers at home than female students.

Professional Development

A majority of mathematics teachers reported that they had received professional development in basic computer skills, software applications, the use of the Internet, and integrating technology into the curriculum. However, a majority of students reported that they never used computers in their mathematics class. This finding suggests a disconnect between teachers’ professional development and the implementation of computers in instruction.

Logistic regression analysis of the relationships between teachers’ exposure to professional development in technology and teachers’ use of computers in the classroom, while significant, were small. This indicates that teachers who participated in professional development in the use of computers were significantly more likely to use computers in the classroom–but only minimally so. In general, teachers’ participation in software application, integrating technology, and advanced training generated the greatest odds of use on all computer applications but one, review math work. These findings confirm research that links professional development to increased use of technology (Silvernail & Harris, 2003; Shapely et al., 2010; Vanatta & Fordham, 2004) and support the TPCK framework, which postulates that providing teachers with professional development on technology that is applicable to instruction increases teachers' use of technology in the classroom (Mishra & Koehler, 2006).

Further, analysis of teachers' exposure to professional development in technology revealed no significant differences between the mathematics performance of students whose teachers reported receiving professional development and students whose teachers did not report receiving professional development across all measures. This means that, when controlling for demographic variables, teachers' participation in professional development in technology was unrelated to student achievement in mathematics.

Research has indicated that it takes a great deal of time for teachers to fully master a new skill, and most teachers do not receive the recommended amount of professional development necessary to master new skills (Darling-Hammond et al., 2009; Kleiman, 2000). The low percentage of teachers reporting that they received follow-up or advanced training (44%) may serve as an indication that few teachers received professional development of sufficient duration and depth to fully implement technology in the classroom. Unfortunately, the measures of professional development in the ELS:2002 dataset were dichotomous—teachers indicated that they had received professional development or they had not. There was no measure of the quantity or quality of the professional development received, which makes it difficult to make inferences from the analysis of the data. However, the findings of this study indicate that professional development in technology is not associated with better achievement outcomes in mathematics.

Limitations of the Study

Although there are several advantages to utilizing a large scale national data set, notably (a) sufficient power to discern statistical significance, (b) generalizability because of the representative nature of those sampled, (c) access to dozens of student- and teacher-reported variables related to computer technology in mathematics classrooms, there were a few limitations to using the ELS:2002. Because the subjects in this study are 10th grade students, the external generalizability of the results is limited. The relationship between the use of technology in the classroom and student achievement has been found to vary by subject and grade level (Antonietti & Giorgetti, 2006; Barron et al., 2001; Bebell & Kay, 2010; Becker, 2001; Cuban et al., 2001; Dunleavy & Heinecke, 2008; Grimes & Warschauer, 2008; Sclater et al., 2006; Wenglinsky, 1998), so the findings of this study may not be applicable to students in other grade levels and other subjects. Additionally, the relationship between professional development in technology and teachers' technology use may vary by discipline and by school level, so it is possible that the findings of this study are only applicable to high school mathematics teachers.

The decision to dichotomize the variables measuring the manner in which computers were used in mathematics (BYS31A-H) resulted in the loss of a degree of precision. By dichotomizing the variables, the values no longer represented the frequency of use, but simply the presence of use. It is possible that differences in student achievement exist between students who use computers for certain tasks everyday or almost everyday and those who use computers rarely. Dichotomizing these variables removed the ability to identify such differences.

The variables measuring mathematics teachers' exposure to professional development in technology were limited to a dichotomous ("Yes" or "No") response. This prevented a thorough analysis of the quantity and quality of the professional development teachers received. Research suggests that professional development should be of sufficient duration and quality to engender changes in teaching practice. This study was not able to fully explore these measures.

The use of a secondary dataset limited the ability to interpret the results of the analysis. For example, the positive relationship between the use of computers to apply learning in students' mathematics class and student achievement was limited by the vagueness of the application: apply learning how? The positive relationship between the use of computers at home and student achievement could be more informative if information was available about the manner in which students used their home computer. Was it used for homework, for research, for playing games, or some combination these applications? Did the relationship between achievement and home computer use vary according to applications of the home computer? This study was not able to address such questions.

Finally, the data analyzed in this study reflects the use of computers, and the relationships between such use and student achievement, in 2002. Technology is a rapidly changing tool, and the amount of money and effort invested in technology in education has only increased in the interim. It is possible that, with changes in technology, the advances in technology's applicability to education, and teachers' increasing awareness of the potential applications of technology in instruction, more current data may provide different results. However, many of the findings of this study confirm existing research–even research conducted within the last couple of years (e.g., Corn et al., 2011; Shapely et al., 2010). This suggests that, although technology has changed in the past nine years, the use of technology in education, by and large, has not. Until there is another sufficiently large data set concerning technology use, we will not be able to establish more current trends.

Future Research

There is a need for further investigations of the application of computer technology in mathematics and its relationship to student achievement. This study was limited in its ability to pinpoint the relationships between the application of computers in the classroom and student achievement by the dichotomization of the variables. Despite this limitation, two applications of computers were found to be significant predictors of student achievement. One of these predictors represented a positive relationship, and one represented a negative relationship. These findings support the existing body of research, which suggests that achievement outcomes vary according to the manner in which technology is used in instruction (Becker, 2001; Lei & Zhao, 2007; Warschauer et al., 2004; Wenglinsky, 1998). Lei and Zhao (2007) found that the relationship between technology use and student achievement varied by the duration of the technology use. Such information was unavailable for this study. This study was also limited in its ability to make inferences from the findings due to the somewhat ambiguous nature of the survey items (such as the use of computers to apply learning). A greater understanding of technology applications associated with both positive and negative achievement outcomes could inform best practice and professional development for educators.

In light of recent developments in the applications of instructional technology, a more in-depth analysis of the relationships between specific technology applications and achievement could reveal the tools that most benefit student learning. For example, applications such as Web 2.0, virtual classrooms, formative assessment software, and the use of tablets and smartphones have been increasingly employed in K-12 education in recent years (Brown & Green, 2009; Koedinger et al., 2010). A large-scale analysis of the relationships between these specific tools and achievement could provide relevant information to guide policy decisions. Such analysis should include comparable control groups, or a sufficient number of students not exposed to computer applications, that enable the study to generalize the relationship between the use of the application and achievement. Further, such analysis should include a measure of the frequency with which applications were employed, as achievement has been found to vary by the duration of students' use of technology in the classroom (Lei & Zhao, 2007).

Both male and female students who reported the use of computers to instruct one-on-one had lower achievement scores than students who did not report the use of computers to instruct one-on-one. The significant interaction between gender and the use of computers to instruct one-on-one suggest that female students who may be struggling academically experience greater benefit from the use of computers to instruct one-on-one than male students. This might inform computer-based credit recovery courses offered to struggling students. However, this interpretation is just one possible explanation of this interaction. Additional research into the relationship between the use of computers in instruction and achievement among academically challenged students of both genders could contribute to the body of research.

Numerous studies, including this dissertation, have identified a positive relationship between the use of computers at home and student achievement (Attewell & Battle, 1999; Bebell & Kay, 2010; Fairlie, 2005; Shapley et al., 2010; Wenglinsky, 1998). However, knowledge of this relationship could be more useful if information was available about the manner in which students used their home computer. Research on this relationship, and how this relationship may vary according to the manner in which computers in the home are used, could potentially be used to inform the effective use of computers in the classroom. Further, an interaction between gender and home computer use indicated that frequent use of a home computer was more beneficial, in terms of achievement, for male students than female students. A study focused on this relationship, and the interactions between specific applications of home computers, achievement, and gender, may reveal factors contributing to this disparity.

There is also a need for further research into the relationship between teachers' participation in professional development in technology, the use of technology in the classroom, and student achievement. This study found no relationship between teachers' participation in professional development in technology and student achievement. Further, the relationships between teachers' professional development in computers and the use of computers in the classroom were minimal. These findings suggest that professional development plays an inconsequential role in both the utilization of technology in instruction and in student achievement. However, this study was limited in that the variables related to teachers' professional development were dichotomous, so there was no measure of the quality or quantity/duration of the training. Future research should focus on the relationship between the quality and quantity of professional development in technology, teachers' use of technology in instruction, and student achievement. Research into the most effective methods of instructing future teachers on the use of technology to improve student achievement is necessary, as well. Such research should follow future teachers into the classroom and measure both the technology use and achievement of treatment teachers' students as compared to control group teachers' students. A greater understanding of these relationships could inform both professional development sessions and teacher preparation programs, possibly saving time and money by eliminating training found to be ineffective.

Conclusion

This study adds to the body of research investigating the relationships between teachers' professional development opportunities, the use of computer technology in the classroom, and student achievement. Existing research professes a connection between teachers' exposure to professional development in technology and teachers' use of technology in the classroom (e.g., Darling-Hammond, 1999; Kanaya et al., 2005; King, 2002; Silvernail & Buffington, 2009). This study identified a positive relationship between the two, but the strength of the relationship was fairly small. However, no professional development variables were found to be related to student achievement. The study was limited by the dichotomous nature of the professional development variables, which did not allow for an investigation of the depth, quality, or duration of the professional development offered to teachers.

The use of technology in the classroom was found to be negatively related to student achievement in mathematics. Analysis of specific applications of computer use in the classroom identified a negative relationship between the use of computers to review math work and student achievement. However, the use of computers to apply learning was positively related to student achievement. Analysis of the applications of computer use was somewhat limited, as well, by the dichotomous nature of the variables. This study also identified very low use of computers in mathematics instruction, a finding consistent with the existing body of research (e.g., Becker, 2001; Corn et al., 2011; Cuban et al., 2001; Grimes & Warschauer, 2008; Sclater et al., 2006; Shapely et al., 2009).

Female students reported slightly less frequent use of computers in the classroom than male students at public schools, but slightly greater use of computers for specific applications at private schools. The significant interaction between gender and the use of computers to instruct one-on-one suggests that female students who may be struggling academically experience greater benefit from the use of computers to instruct one-on-one than male students. Additional analysis of the applications of computer variables, dummy-coded by frequency of use to allow for a more thorough inspection, revealed more interactions between specific frequencies of use and gender. Specifically, the use of computers to review math work everyday or almost everyday, for graphing less than once a week, and to show new topics once or twice a week were all significant. Further investigation revealed a negative relationship between each application and achievement for both males and females, although the relationship was more negative for male students than female students.

Recent years have been challenging for states and LEAs, as they have been faced with fiscal crises and difficult choices, particularly in education. Thousands of teaching positions have been eliminated as millions of dollars were invested in instructional technology. Advocates of technology in education have research to substantiate their support. There are several studies that have, in fact, identified positive student outcomes of technology initiatives achievement (Campuzano et al., 2009; Hunter & Greever-Rice, 2007; Lowther et al., 2003; Mollette et al., 2010; Shapley et al., 2010). However, technology cannot serve as a cure-all for all that ails of American K-12 education. The studies that have identified no relationship, and especially those that have identified a negative relationship, between technology use in the classroom and student achievement should give even the most fervent advocates of technology in education pause.

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Appendices

Appendix A

Histograms of Non-Dichotomous Variables

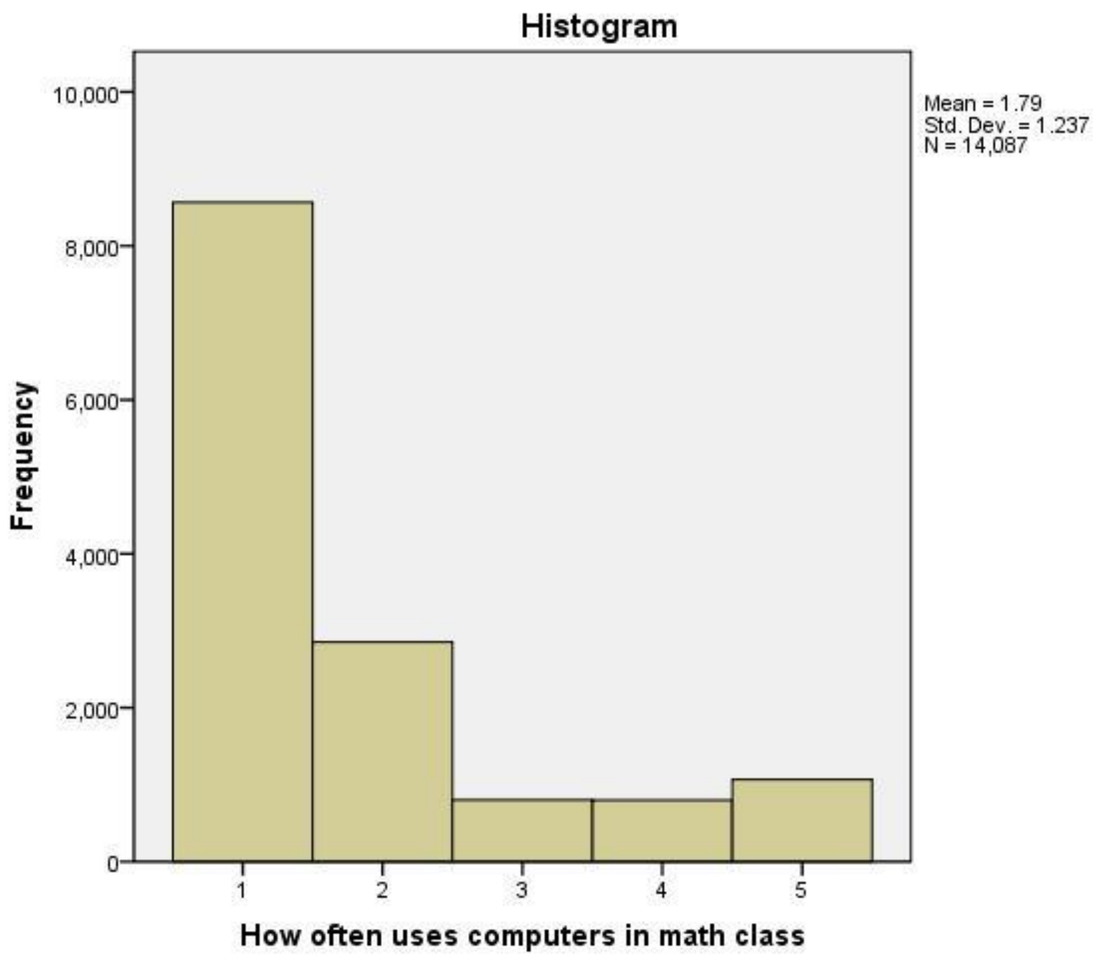

Figure A1. Histogram of responses to “How often uses computers in math class”

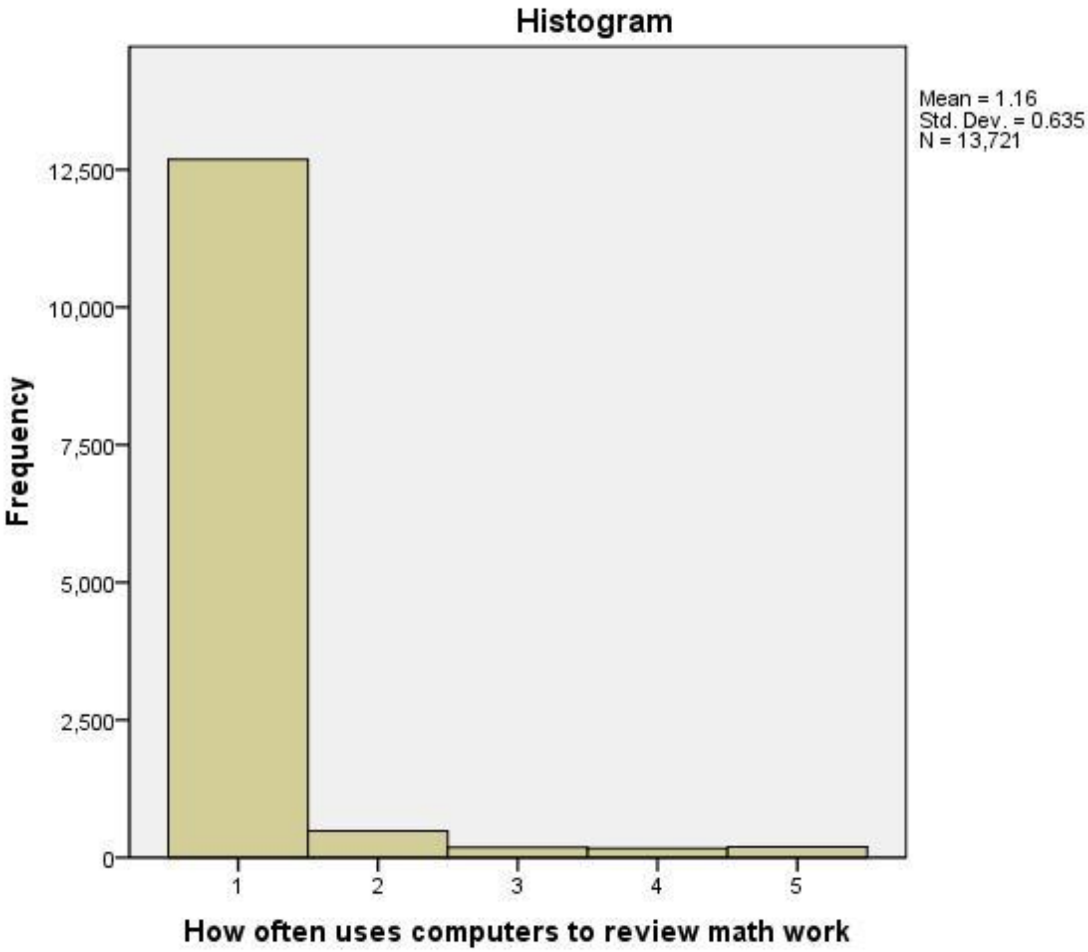

Figure A2. Histogram of responses to “How often uses computers to review math work”

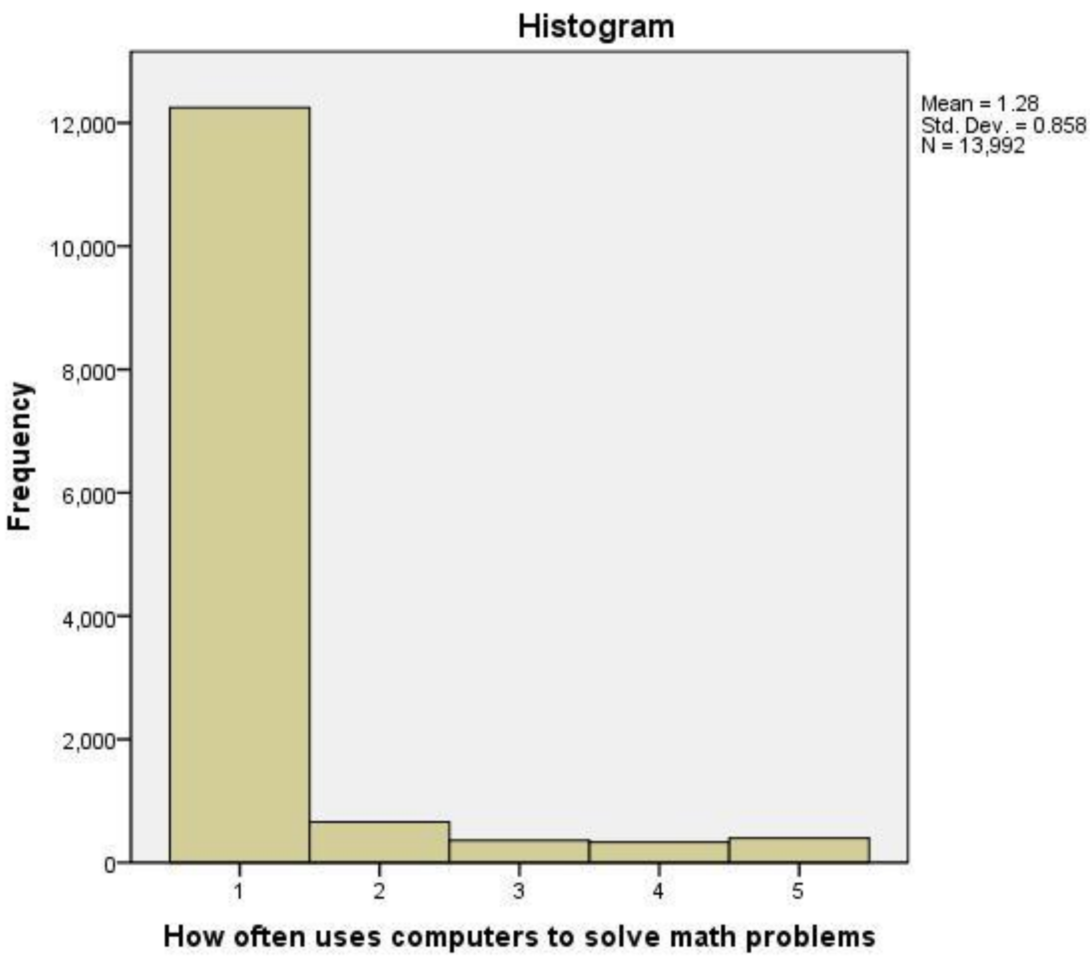

Figure A3. Histogram of responses to “How often uses computers to solve math problems”

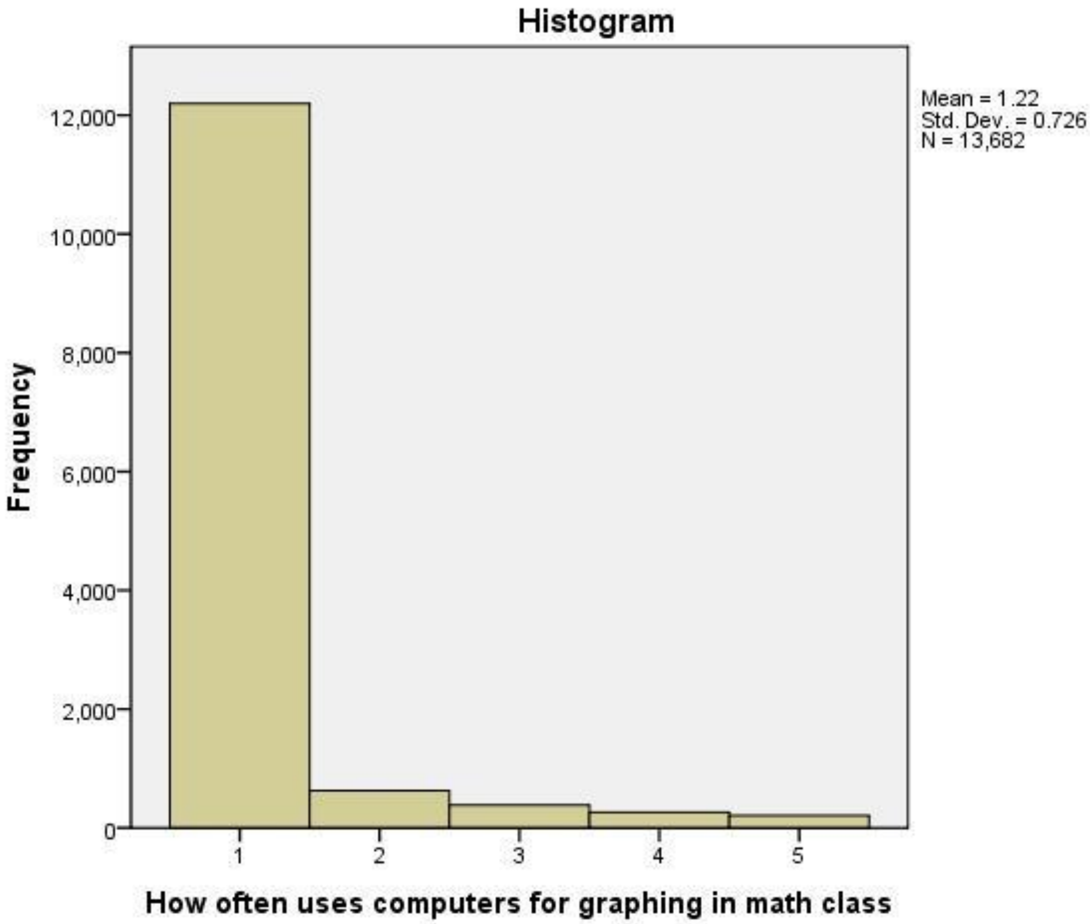

Figure A4. Histogram of responses to "How often uses computers for graphing in math class"

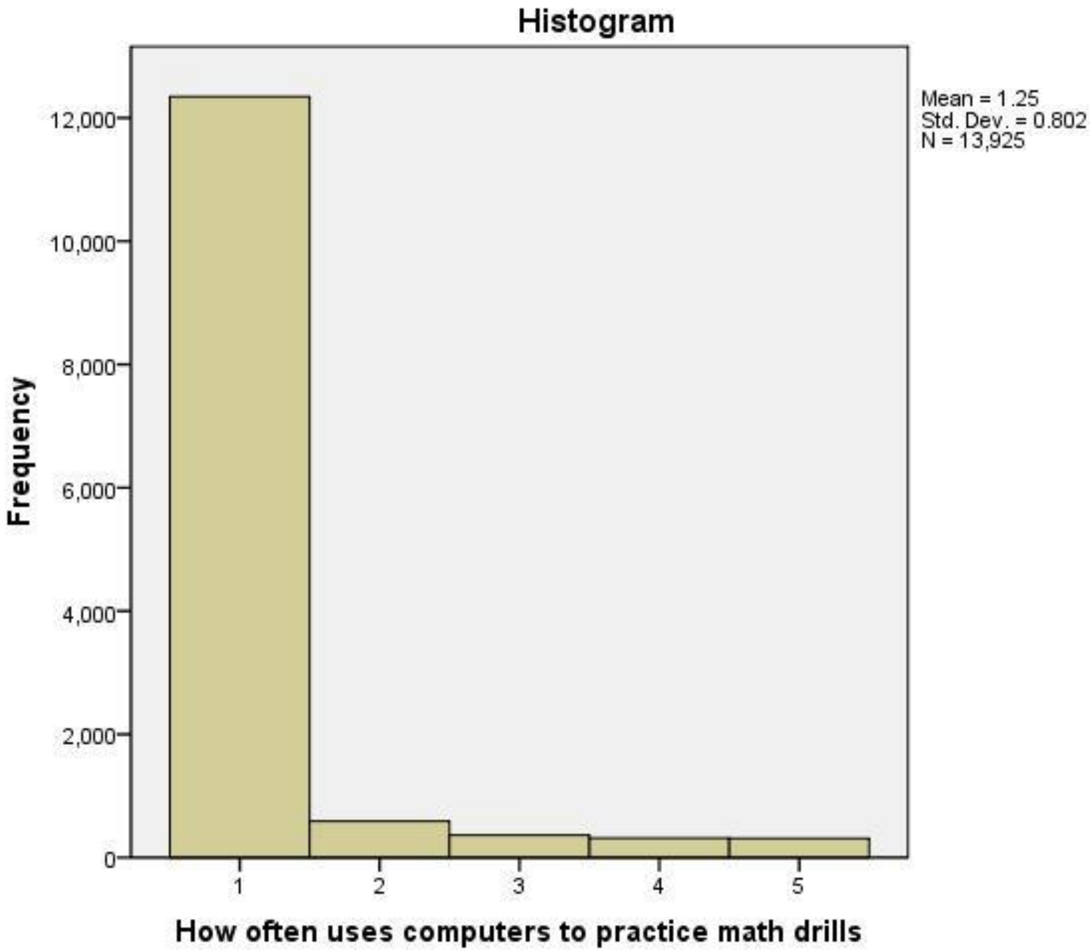

Figure A5. Histogram of responses to "How often uses computers to practice math drills"

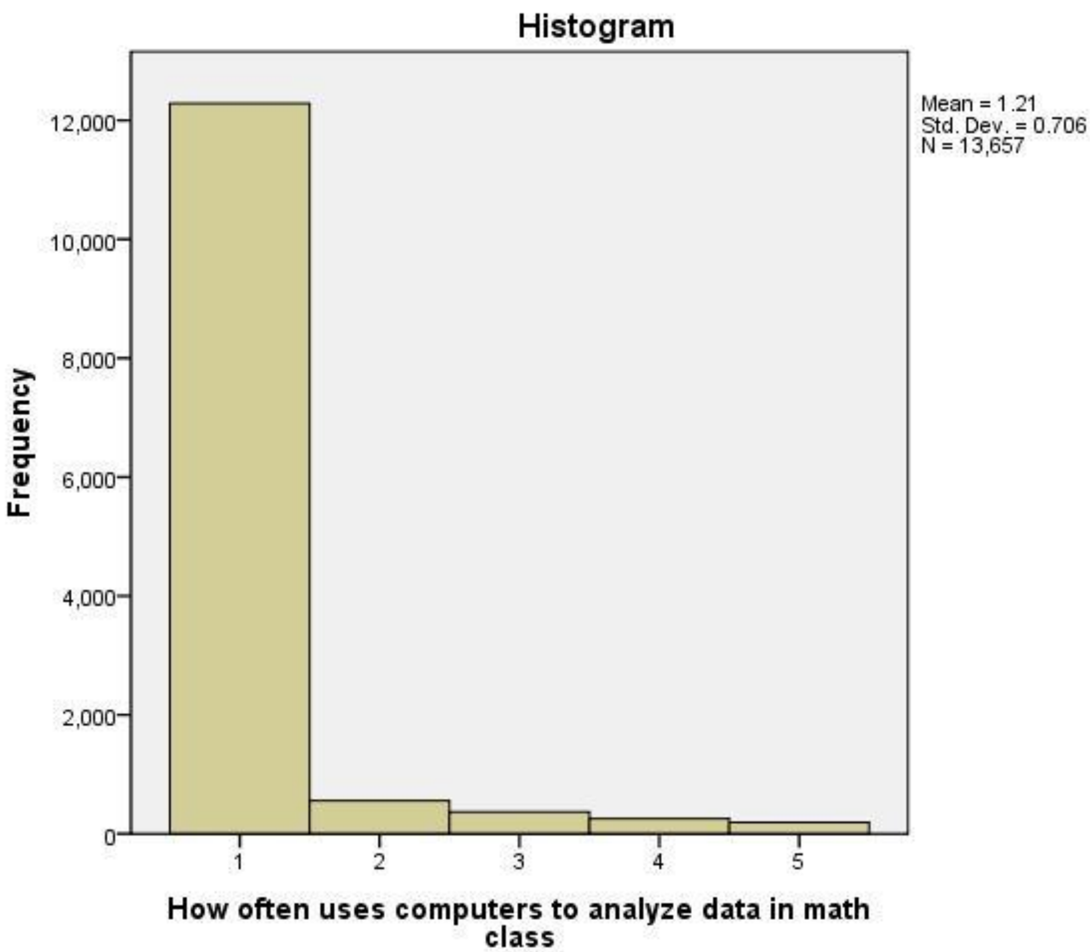

Figure A6. Histogram of responses to "How often uses computers to analyze data in math class"

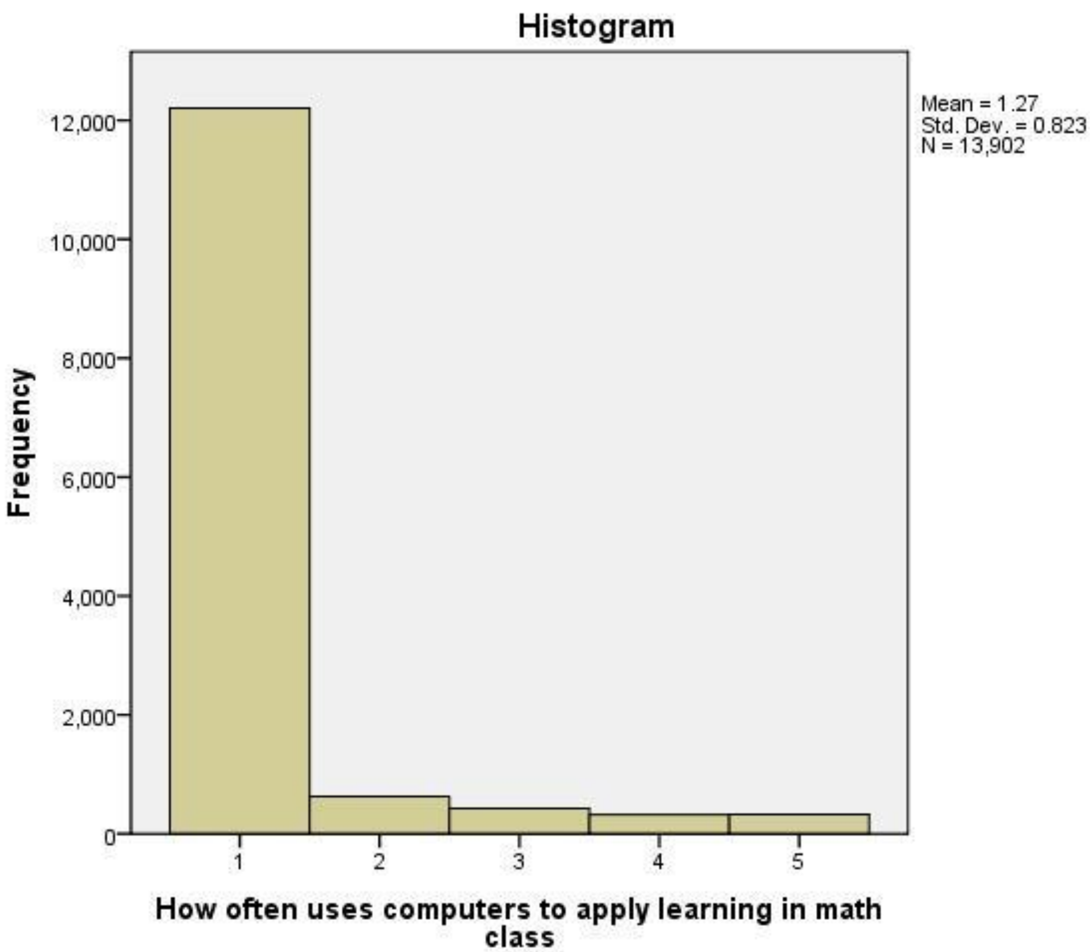

Figure A7. Histogram of responses to "How often uses computers to apply learning in math class"

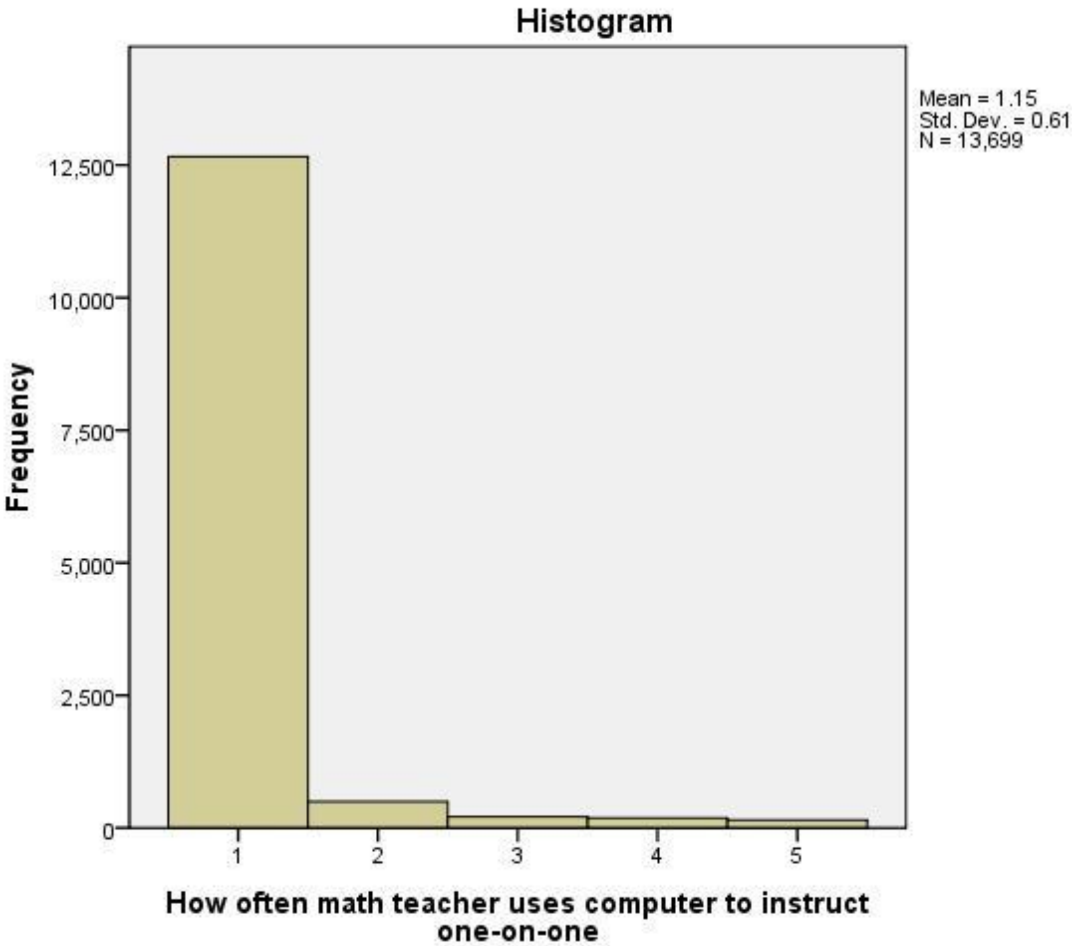

Figure A8. Histogram of responses to “How often math teacher uses computer to instruct one-on-one”

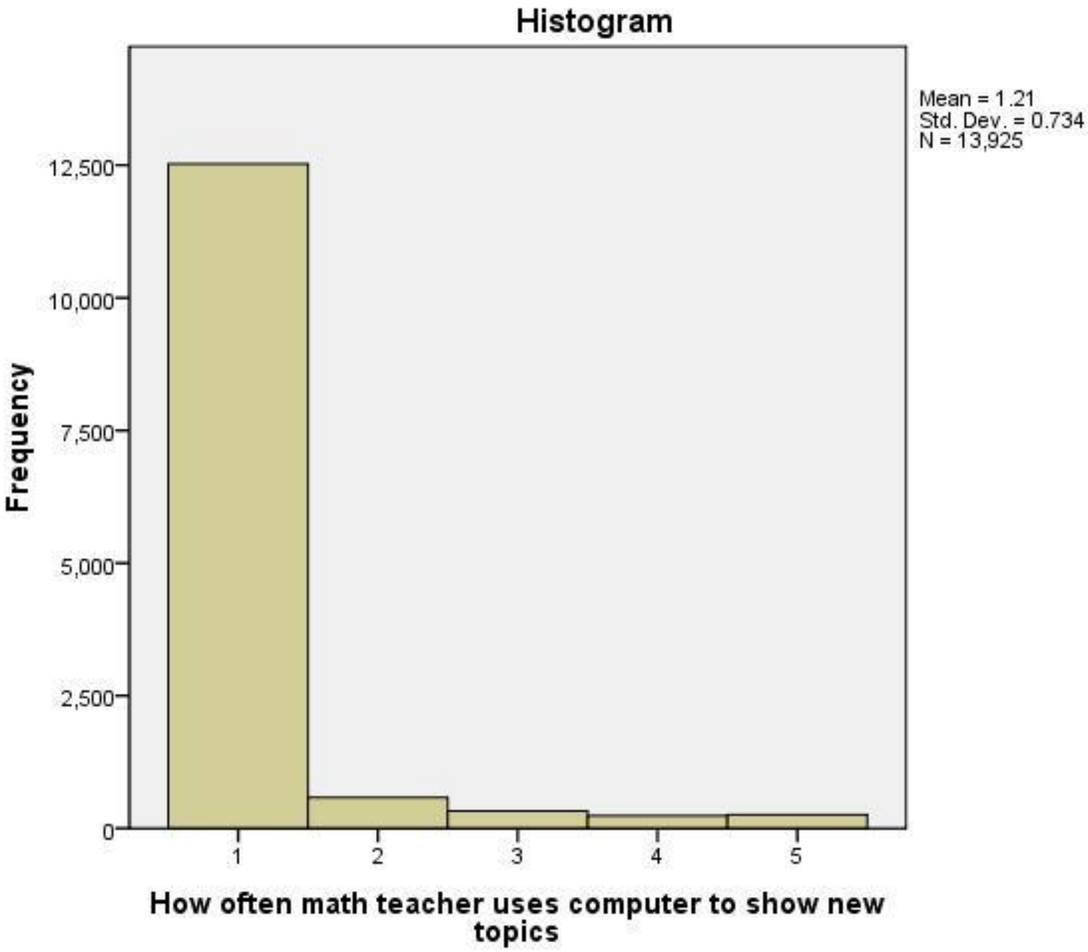

Figure A9. Histogram of responses to "How often math teacher uses computer to show new topics"

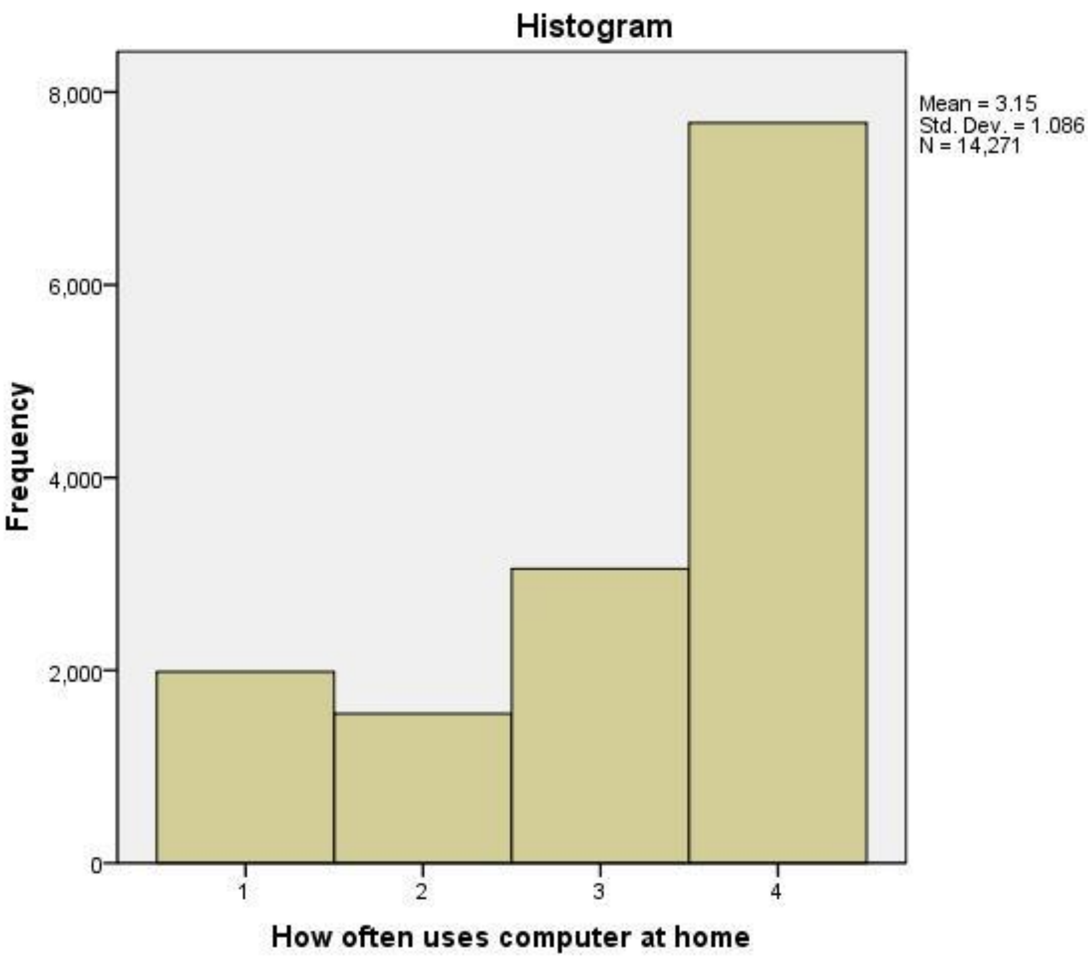

Figure A10. Histogram of responses to "How often uses computer at home"

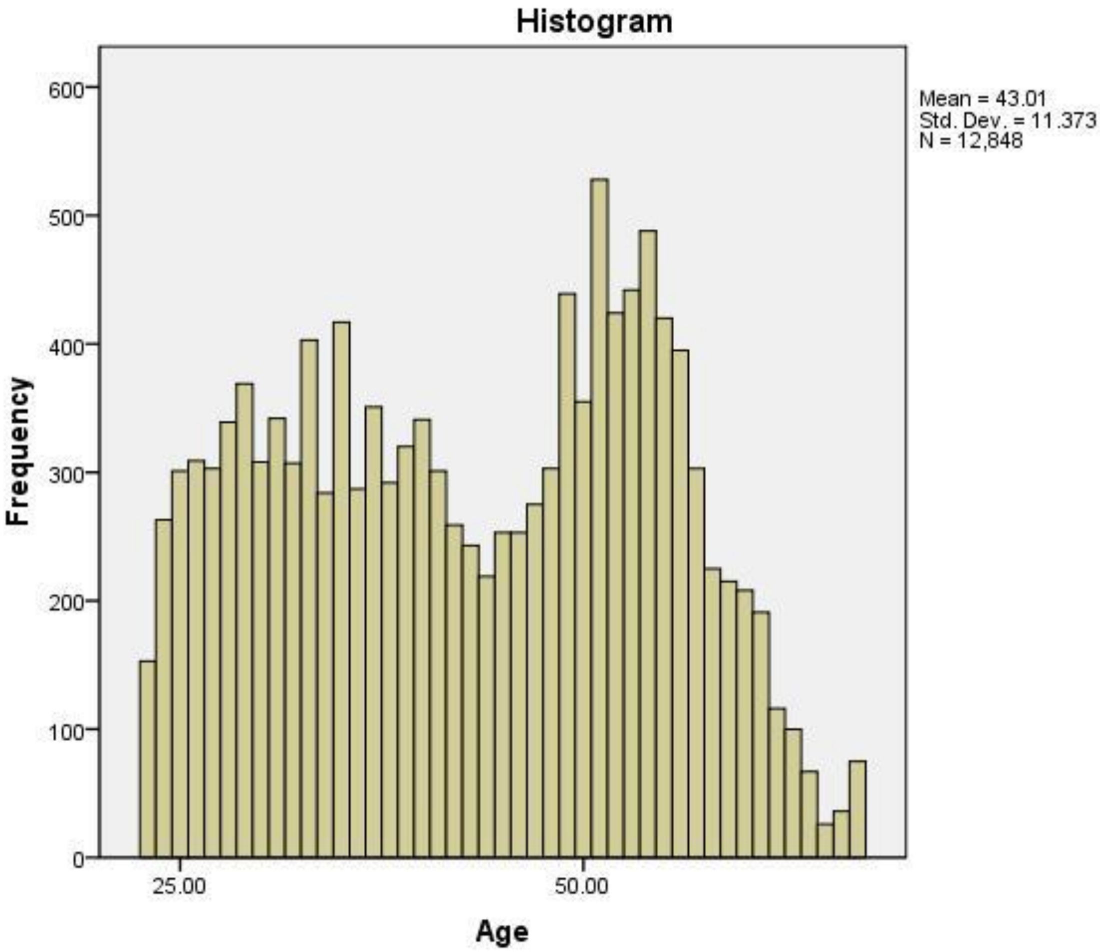

Figure A11. Histogram of responses to “Teacher’s Age”

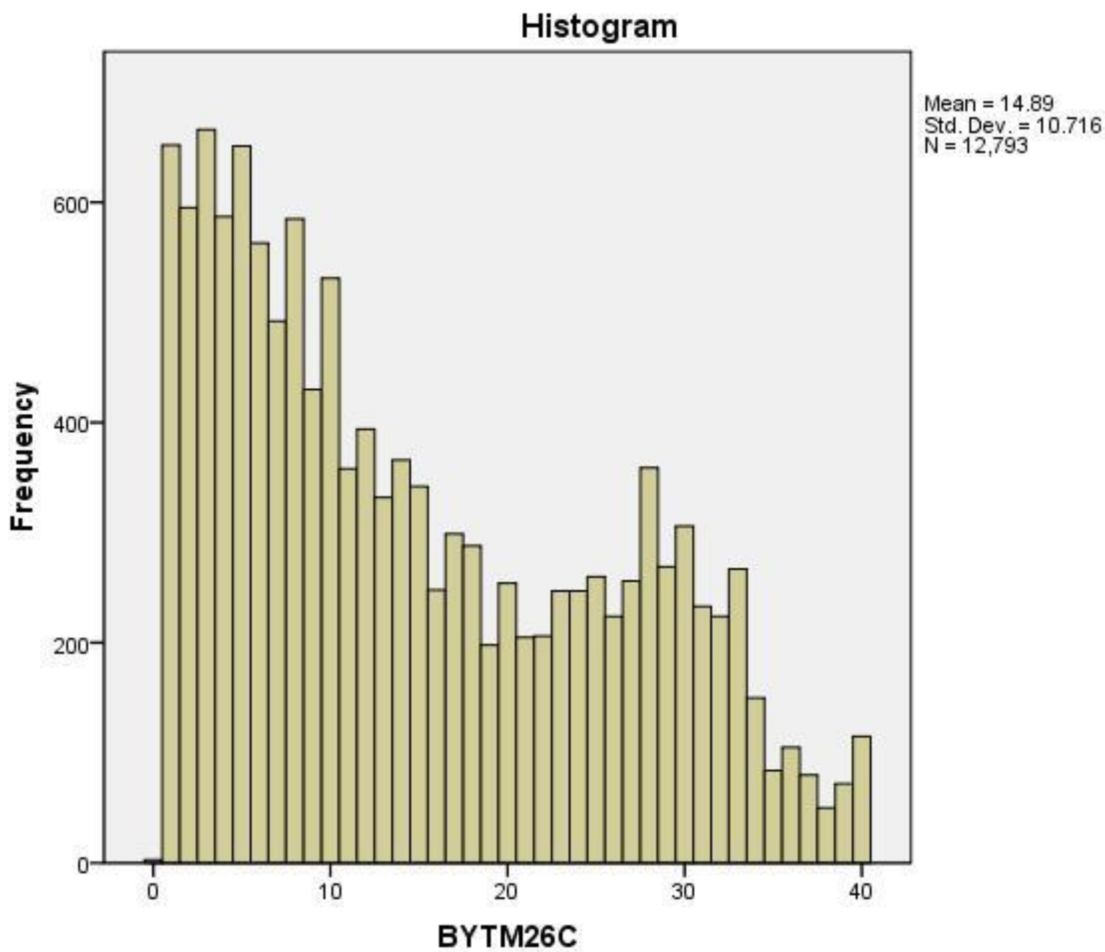

Figure A12. Histogram of responses to "Teacher's years of experience"

Appendix B

Tolerance and VIF Analysis

Table B1

Tolerance and VIF values of independent variables

	Tolerance	VIF
Level 1		
Frequency of computer use	.83	1.21
Review math work	.38	2.61
Solve math problems	.22	4.53
Graphing	.27	3.65
Math drills	.24	4.19
Analyze data	.24	4.20
Apply learning	.22	4.50
Instruct one-on-one	.30	3.31
Show new topics	.30	3.36
Home computer use	.85	1.18
Training in basic computer skills	.65	1.54
Training in software applications	.64	1.56
Training in use of Internet	.62	1.62
Training in other technology	.82	1.23
Training in integrating technology	.70	1.44
Advanced training	.79	1.26
American Indian	.99	1.02
Asian	.98	1.02
Black	.87	1.16
Hispanic	.85	1.17
Multiracial	.97	1.03
Female	.99	1.01
Socioeconomic status	.84	1.19
Teacher’s years of experience	.37	2.71
Teacher’s age	.37	2.71
Level 2		
Catholic	.83	1.20
Non-Catholic private	.86	1.17
Urban	.82	1.23
Rural	.88	1.14
FRL 0 to 5	.45	2.21
FRL 6 to 10	.66	1.52
FRL 11 to 20	.56	1.79
FRL 21 to 30	.59	1.69
FRL 51 to 75	.69	1.45
FRL 76 to 100	.77	1.31

Appendix C

Application of Computers by School FRL and Gender

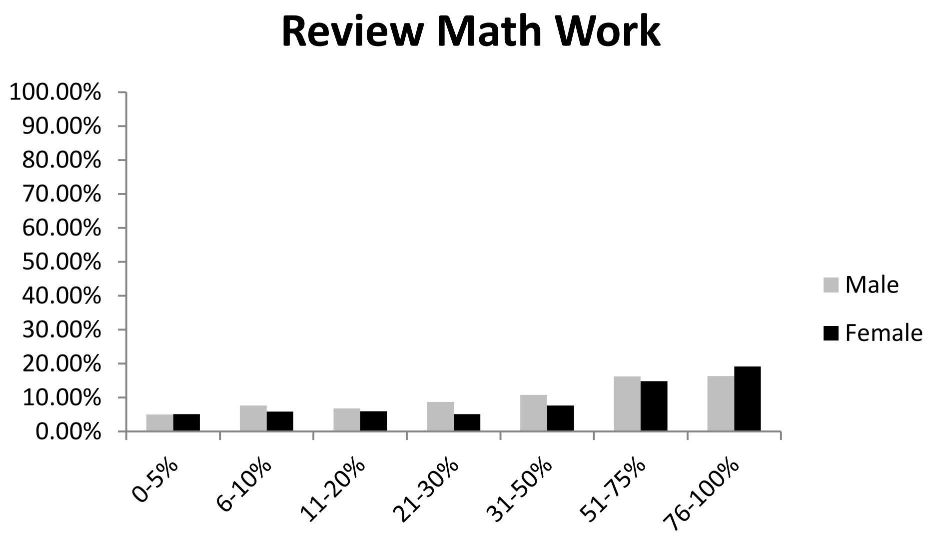

Figure C1. Use of computers to review math work, by school FRL and gender

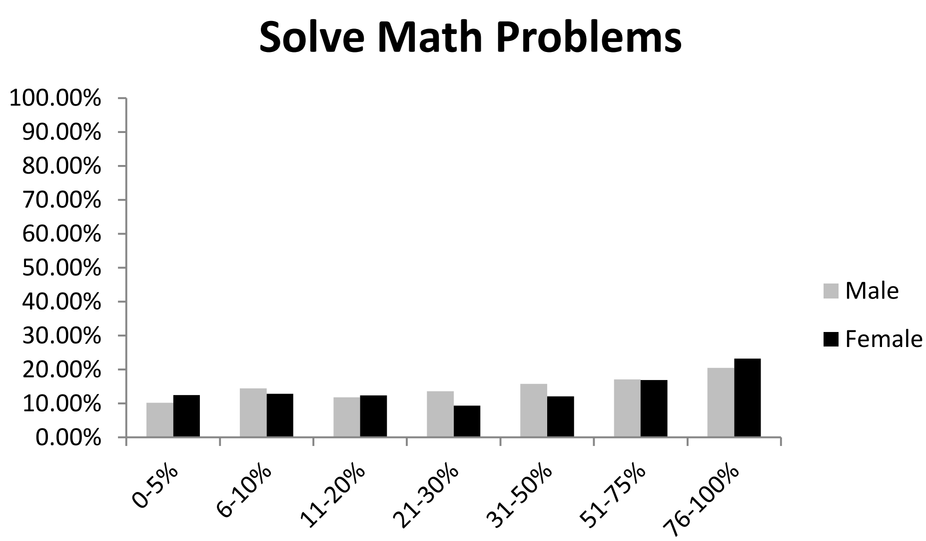

Figure C2. Use of computers to solve math problems, by school FRL and gender

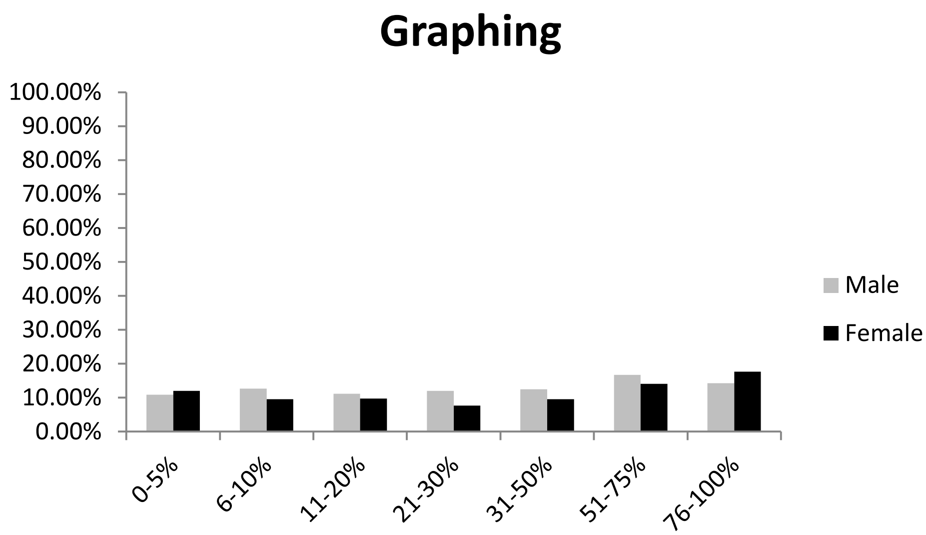

Figure C3. Use of computers for graphing, by school FRL and gender

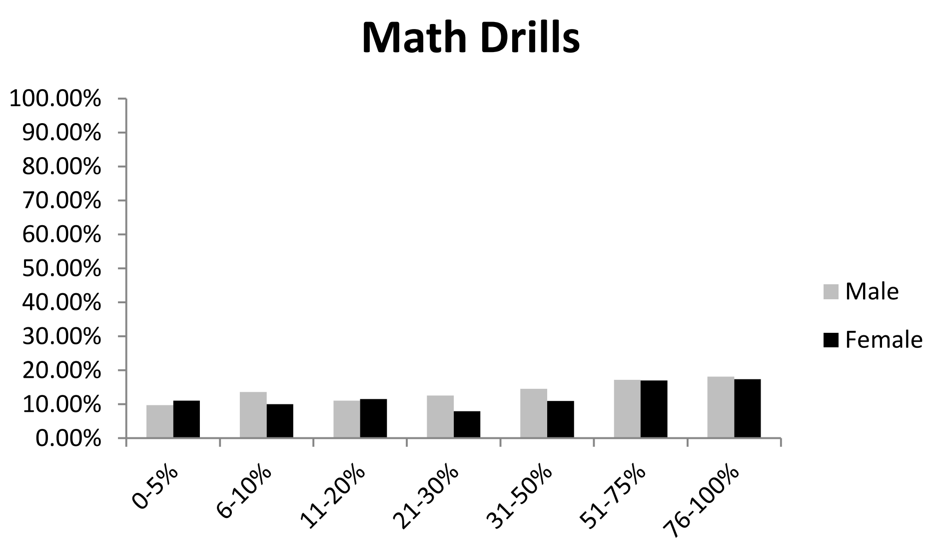

Figure C4. Use of computers for math drills, by school FRL and gender

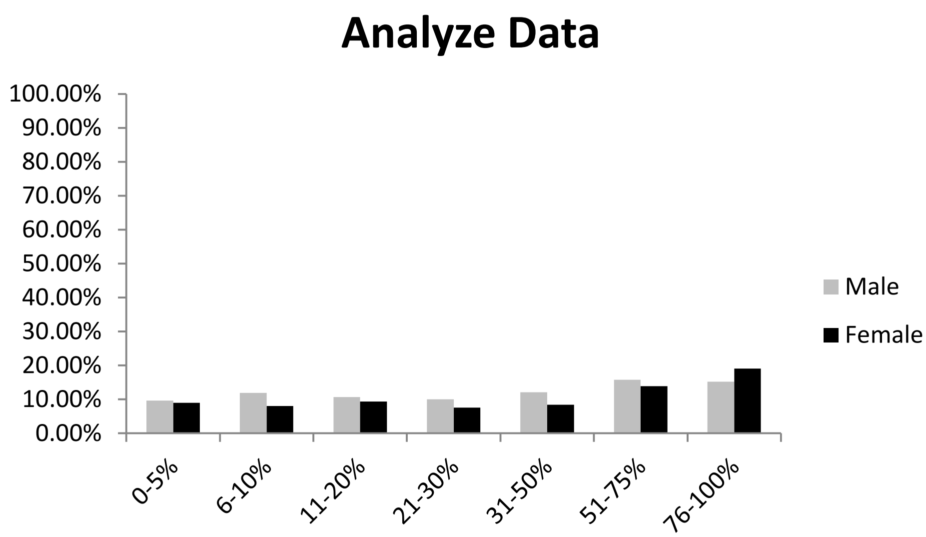

Figure C5. Use of computers to analyze, by school FRL and gender

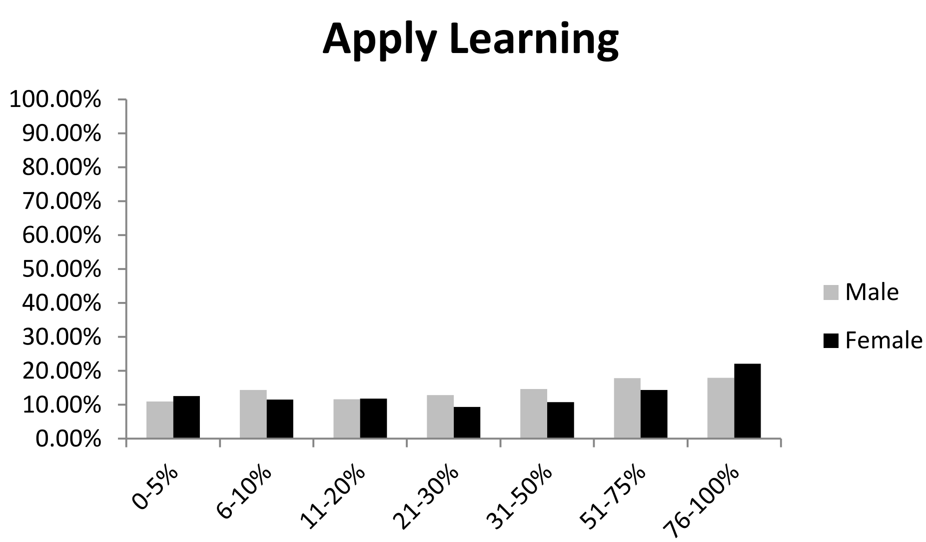

Figure C6. Use of computers to apply learning, by school FRL and gender

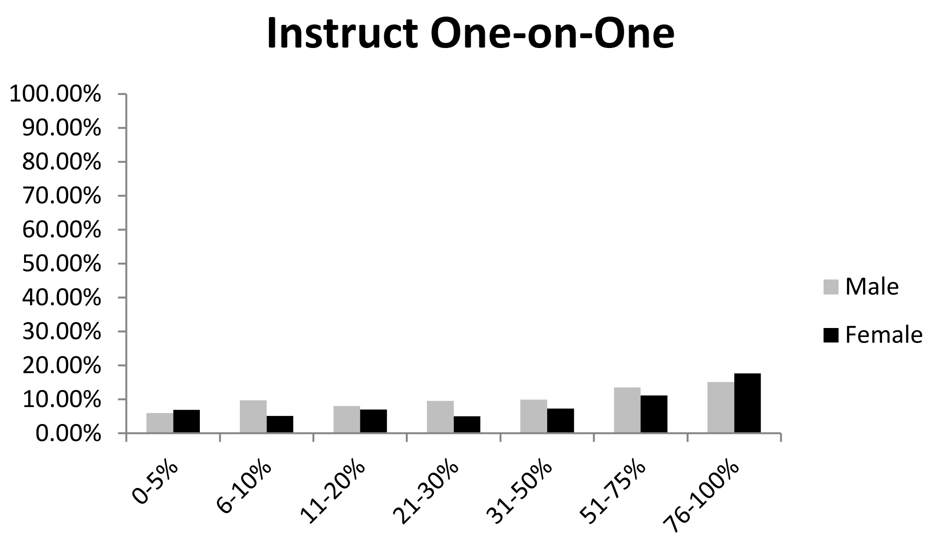

Figure C7. Use of computers to instruct one-on-one, by school FRL and gender

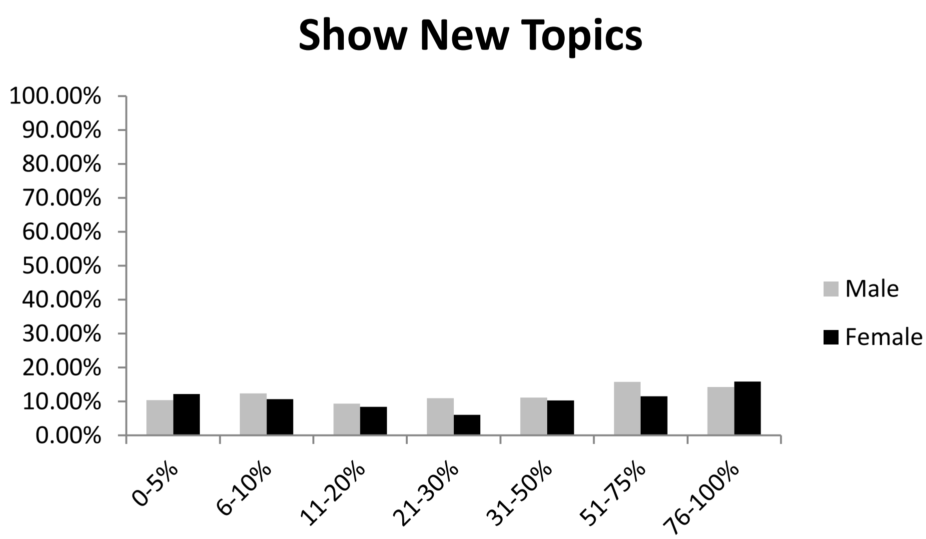

Figure C8. Use of computers to show new topics, by school FRL and gender

Appendix D

Imputed and Weighted Multilevel Model Analysis

Table D1

Model Comparison, Level 1 Only and Level 1 and 2, Imputed and Weighted

	Level 1	Level 1 & Level 2
Level 1		
Standardized math score	51.47	50.40
Computer use		
Frequency of computer use	-1.28***	-1.22***
Review math work	-4.60***	-4.46***
Solve math problems	-0.83	-0.81
Graphing	0.52	0.28
Math drills	-1.25	-1.26
Analyze data	0.87	0.82
Apply learning	2.76**	2.82**
Instruct one-on-one	1.36	1.34
Show new topics	-0.01	0.10
Home computer use	1.33***	1.32***
Professional development		
Training in basic computer skills	-0.33	-0.26
Training in software applications	1.03	0.93
Training in use of Internet	0.21	0.44
Training in other technology	-0.45	-0.54
Training in integrating technology	0.05	0.07
Advanced training	-0.21	-0.15
Student demographics		
American Indian	-3.25***	-2.87**
Asian	2.24**	2.33**
Black	-5.05***	-4.38***
Hispanic	-3.95***	-3.50***
Multiracial	-1.26*	-1.17*
Female	-0.18	-0.12
Socio-economic status	3.40***	3.18***

Table D1 (continued)

	Level 1	Level 1 & Level 2
Teacher demographics		
Teacher's years of experience	0.12***	0.12***
Teacher's age	-0.04	-0.04
Gender interactions		
Female * Frequency of computer use	0.14	0.12
Female * Review math work	0.65	0.77
Female * Solve math problems	0.15	0.23
Female * Graphing	2.06	2.16
Female * Math drills	0.10	-0.02
Female * Analyze data	-2.09	-2.07
Female * Apply Learning	-0.31	-0.30
Female * Instruct one-on-one	-2.81*	-2.73*
Female * Show new topics	1.82	1.64
Female * Training in basic computer skills	0.11	0.15
Female * Training in software applications	-1.28	-1.26
Female * Training in use of Internet	1.24	1.15
Female * Training in other technology	0.29	0.25
Female * Training in integrating technology	0.34	0.38
Female * Advanced training	0.57	0.62
Female * Home computer use	-0.64**	-0.66**
Level 2		
Catholic		0.79
Non-Catholic private		0.44
Urban		-0.36
Rural		0.21
FRL 0 to 5		1.87**
FRL 6 to 10		1.61
FRL 11 to 20		1.12
FRL 21 to 30		-0.31
FRL 51 to 75		-1.08
FRL 76 to 100		-2.24**

Table D1 (continued)

	Level 1	Level 1 & Level 2
Random effect	Variance component	Variance component
Intercept (variance between schools)	57.97	57.85
Level 1 (variance within schools)	7.60	6.55
Intraclass Correlation	.12	.10
Variance in achievement between schools (%) explained		68.99
Variance in achievement within schools (%) explained	20.41	20.57

* $p < .05$; ** $p < .01$; *** $p < .001$

Appendix E

Imputed and Unweighted Multilevel Model Analysis

Table E1

Model Comparison, Level 1 Only and Level 1 and 2, Unweighted and Imputed

	Level 1	Level 1 & Level 2
Level 1		
Standardized math score	52.03	50.45
Computer use		
Frequency of computer use	-1.20***	-1.18***
Review math work	-3.12***	-3.05***
Solve math problems	-0.72	-0.71
Graphing	0.89	0.82
Math drills	-1.13	-1.08
Analyze data	1.71*	1.71*
Apply learning	1.18	1.12
Instruct one-on-one	-1.17	-1.12
Show new topics	0.26	0.23
Home computer use	1.53***	1.48***
Professional development		
Training in basic computer skills	-0.73	-0.69
Training in software applications	0.55	0.56
Training in use of Internet	-0.00	0.11
Training in other technology	-0.00	-0.04
Training in integrating technology	0.12	0.14
Advanced training	0.06	0.10
Student demographics		
American Indian	-2.89**	-2.41*
Asian	1.39***	1.63***
Black	-4.97***	-4.63***
Hispanic	-3.54***	-3.26***
Multiracial	-1.41***	-1.27**
Female	-0.10	-0.03
Socio-economic status	3.45***	3.21***

Table E1 (continued)

	Level 1	Level 1 & Level 2
Teacher demographics		
Teacher’s years of experience	0.08***	0.09***
Teacher’s age	-0.01	-0.01
Gender interactions		
Female * Frequency of computer use	0.32	0.35
Female * Review math work	-0.02	-0.02
Female * Solve math problems	0.13	0.09
Female * Graphing	0.07	0.08
Female * Math drills	0.22	0.20
Female * Analyze data	0.15	0.16
Female * Apply Learning	0.17	0.14
Female * Instruct one-on-one	0.01	0.07
Female * Show new topics	-0.36	-0.35
Female * Training in basic computer skills	0.23	0.21
Female * Training in software applications	1.02	0.97
Female * Training in use of Internet	-1.53	-1.44
Female * Training in other technology	-0.35	-0.32
Female * Training in integrating technology	-1.95	-1.89
Female * Advanced training	3.23**	3.12**
Female * Home computer use	-0.64***	-0.64***
Level 2		
Catholic		0.37
Non-Catholic private		0.68
Urban		-0.13
Rural		-0.18
FRL 0 to 5		2.62***
FRL 6 to 10		2.09***
FRL 11 to 20		1.30**
FRL 21 to 30		0.45
FRL 51 to 75		-0.30
FRL 76 to 100		-1.29

Table E1 (continued)

	Level 1	Level 1 & Level 2
Random effect	Variance component	Variance component
Intercept (variance between schools)	62.21	62.12
Level 1 (variance within schools)	7.69	6.48
Intraclass Correlation	.11	.09
Variance in achievement between schools (%) explained		69.36
Variance in achievement within schools (%) explained	14.59	14.72

* $p < .05$; ** $p < .01$; *** $p < .001$

Appendix F

Non-imputed and Unweighted Multilevel Model Analysis

Table F1

Model Comparison, Level 1 Only and Level 1 and 2, Unweighted and Non-imputed

	Level 1	Level 1 & Level 2
Level 1		
Standardized math score	52.12	50.68
Computer use		
Frequency of computer use	-1.20***	-1.17***
Review math work	-3.70***	-3.63***
Solve math problems	-0.92	-0.86
Graphing	0.98	0.86
Math drills	-1.97*	-1.94*
Analyze data	1.89*	1.92*
Apply learning	2.02*	1.92*
Instruct one-on-one	-0.50	-0.45
Show new topics	0.21	0.23
Home computer use	1.64***	1.59***
Professional development		
Training in basic computer skills	-0.80*	-0.75
Training in software applications	0.43	0.45
Training in use of Internet	0.15	0.27
Training in other technology	-0.15	-0.19
Training in integrating technology	0.17	0.16
Advanced training	0.09	0.13
Student demographics		
American Indian	-2.64*	-2.24*
Asian	1.50***	1.73***
Black	-4.82***	-4.49***
Hispanic	-3.50***	-3.23***
Multiracial	-1.25**	-1.13**
Female	0.04	0.08
Socio-economic status	3.37***	3.13***

Table F1 (continued)

	Level 1	Level 1 & Level 2
Teacher demographics		
Teacher's years of experience	0.10***	0.10***
Teacher's age	-0.01	-0.02
Gender interactions		
Female * Frequency of computer use	0.17	0.15
Female * Review math work	0.23	0.29
Female * Solve math problems	-0.14	-0.16
Female * Graphing	0.05	0.06
Female * Math drills	1.87	1.86
Female * Analyze data	-1.59	-1.52
Female * Apply Learning	-1.11	-1.04
Female * Instruct one-on-one	-2.32*	-2.24
Female * Show new topics	3.20**	3.03**
Female * Training in basic computer skills	0.35	0.39
Female * Training in software applications	0.07	0.07
Female * Training in use of Internet	-0.02	-0.07
Female * Training in other technology	0.22	0.22
Female * Training in integrating technology	0.15	0.15
Female * Advanced training	0.15	0.17
Female * Home computer use	-0.72***	-0.73***
Level 2		
Catholic		0.34
Non-Catholic private		0.58
Urban		-0.15
Rural		-0.23
FRL 0 to 5		2.52***
FRL 6 to 10		2.08***
FRL 11 to 20		1.16*
FRL 21 to 30		0.30
FRL 51 to 75		-0.39
FRL 76 to 100		-1.31

Table F1 (continued)

	Level 1	Level 1 & Level 2
Random effect	Variance component	Variance component
Intercept (variance between schools)	60.56	60.47
Level 1 (variance within schools)	7.69	6.53
Intraclass Correlation	.11	.10
Variance in achievement between schools (%) explained		69.09
Variance in achievement within schools (%) explained	16.86	16.98

* *p* < .05; ** *p* < .01; *** *p* < .001

Appendix G

MLM Model Comparison

Table G1

Model Comparison: Imputed and Weighted, Imputed and Unweighted, Non-imputed and Weighted, and Non-imputed and Unweighted

	Imputed and weighted		Imputed and unweighted		Non-imputed and unweighted		Non-imputed and weighted	
	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2
Level 1								
Standardized math score	51.47	50.40	52.03	50.45	52.12	50.68	51.47***	50.40***
Computer use								
Frequency of computer use	-1.28***	-1.22***	-1.20***	-1.18***	-1.20***	-1.17***	-1.25***	-1.22***
Review math work	-4.60***	-4.46***	-3.12***	-3.05***	-3.70***	-3.63***	-4.60***	-4.46***
Solve math problems	-0.83	-0.81	-0.72	-0.71	-0.92	-0.86	-0.83	-0.81
Graphing	0.52	0.28	0.89	0.82	0.98	0.86	0.52	0.28
Math drills	-1.25	-1.26	-1.13	-1.08	-1.97*	-1.94*	-1.25	-1.26
Analyze data	0.87	0.82	1.71*	1.71*	1.89*	1.92*	0.87	0.83
Apply learning	2.76**	2.82**	1.18	1.12	2.02*	1.92*	2.76**	2.81**
Instruct one-on-one	1.36	1.34	-1.17	-1.12	-0.50	-0.45	1.36	1.34
Show new topics	-0.01	0.10	0.26	0.23	0.21	0.23	-0.01	0.10
Home computer use	1.33***	1.32***	1.53***	1.48***	1.64***	1.59***	1.33***	1.33***

Table G1 (continued)

	Imputed and weighted		Imputed and unweighted		Non-imputed and unweighted		Non-imputed and weighted	
	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2
Professional development								
Training in basic computer skills	-0.33	-0.26	-0.73	-0.69	-0.80*	-0.75	-0.33	-0.26
Training in software applications	1.03	0.93	0.55	0.56	0.43	0.45	1.03	0.93
Training in use of Internet	0.21	0.44	-0.00	0.11	0.15	0.27	0.21	0.45
Training in integrating technology	0.05	0.07	0.12	0.14	0.17	0.16	0.05	0.07
Advanced training	-0.21	-0.15	0.06	0.10	0.09	0.13	-0.21	-0.15
Student demographics								
American Indian	-3.25***	-2.87**	-2.89**	-2.41*	-2.64*	-2.24*	-3.25***	-2.87**
Asian	2.24**	2.33**	1.39***	1.63***	1.50***	1.73***	2.24**	2.33**
Black	-5.05***	-4.38***	-4.97***	-4.63***	-4.82***	-4.49***	-5.05***	-4.38***
Hispanic	-3.95***	-3.50***	-3.54***	-3.26***	-3.50***	-3.23***	-3.95***	-3.50***
Multiracial	-1.26*	-1.17*	-1.41***	-1.27**	-1.25**	-1.13**	-1.26*	-1.17*
Female	-0.18	-0.12	-0.10	-0.03	0.04	0.08	-0.18	-0.12
Socio-economic status	3.40***	3.18***	3.45***	3.21***	3.37***	3.13***	3.40***	3.18***
Teacher demographics								
Teacher's years of experience	0.12***	0.12***	0.08***	0.09***	0.10***	0.10***	0.12***	0.12***
Teacher's age	-0.04	-0.04	-0.01	-0.01	-0.01	-0.02	-0.04	-0.04
Gender interactions								
Female * Frequency of computer use	0.14	0.12	0.32	0.35	0.17	0.15	0.14	0.12

Table G1 (continued)

	Imputed and weighted		Imputed and unweighted		Non-imputed and unweighted		Non-imputed and weighted	
	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2
Female * Review math work	0.65	0.77	-0.02	-0.02	0.23	0.29	0.65	0.77
Female * Solve math problems	0.15	0.23	0.13	0.09	-0.14	-0.16	0.15	0.23
Female * Graphing	2.06	2.16	0.07	0.08	0.05	0.06	2.06	2.16
Female * Math drills	0.10	-0.02	0.22	0.20	1.87	1.86	0.10	-0.02
Female * Analyze data	-2.09	-2.07	0.15	0.16	-1.59	-1.52	-2.09	-2.07
Female * Apply Learning	-0.31	-0.30	0.17	0.14	-1.11	-1.04	-0.31	-0.30
Female * Instruct one-on-one	-2.81*	-2.73*	0.01	0.07	-2.32*	-2.24	-2.81*	-2.73*
Female * Show new topics	1.82	1.64	-0.36	-0.35	3.20**	3.03**	1.82	1.64
Female * Training in basic computer skills	0.11	0.15	0.23	0.21	0.35	0.39	0.11	0.15
Female * Training in software applications	-1.28	-1.26	1.02	0.97	0.07	0.07	-1.28	-1.26
Female * Training in use of Internet	1.24	1.15	-1.53	-1.44	-0.02	-0.07	1.24	1.15
Female * Training in other technology	0.29	0.25	-0.35	-0.32	0.22	0.22	0.29	0.25
Female * Training in integrating technology	0.34	0.38	-1.95	-1.89	0.15	0.15	0.34	0.38
Female * Advanced training	0.57	0.62	3.23**	3.12**	0.15	0.17	0.57	0.62
Female * Home computer use	-0.64**	-0.66**	-0.64***	-0.64***	-0.72***	-0.73***	-0.64**	-0.66**
Level 2								
Catholic		0.79		0.37		0.34		0.79
Non-Catholic private		0.44		0.68		0.58		0.44
Urban		-0.36		-0.13		-0.15		-0.36
Rural		0.21		-0.18		-0.23		0.20

Table G1 (continued)

	Imputed and weighted		Imputed and unweighted		Non-imputed and unweighted		Non-imputed and weighted	
	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2	Level 1	Level 1 & Level 2
FRL 0 to 5		1.87**		2.62***		2.52***		1.87**
FRL 6 to 10		1.61		2.09***		2.08***		1.61
FRL 11 to 20		1.12		1.30**		1.16*		1.12
FRL 21 to 30		-0.31		0.45		0.30		-0.31
FRL 51 to 75		-1.08		-0.30		-0.39		-1.08
FRL 76 to 100		-2.24**		-1.29		-1.31		-2.24**
Random effect	Variance component		Variance component		Variance component		Variance component	
Intercept (variance between schools)	57.97	57.85	62.21	62.12	60.56	60.47	57.97	57.85
Level 1 (variance within schools)	7.60	6.55	7.69	6.48	7.69	6.53	7.60	6.55
Intraclass Correlation	.12	.10	.11	.09	.11	.10	.12	.10
Variance in ach. between schools (%) explained		68.99		69.36		69.09		69.00
Variance in ach. within schools (%) explained	20.41	20.57	14.59	14.72	16.86	16.98	20.41	20.57

* $p < .05$; ** $p < .01$; *** $p < .001$

Appendix H

Dummy-Coded Multilevel Model Analysis

Table H1

Model Comparison, Level 1 Only and Level 1 and 2, Weighted and Non-imputed

	Level 1	Level 1 & Level 2
Level 1		
Standardized math score	51.39	50.35
Computer use		
Frequency of computer use	-1.28***	-1.25***
Reviews math work rarely	-2.85	-2.81
Reviews math work less than once a week	-7.93***	-7.60**
Reviews math work once or twice a week	-5.01*	-4.58*
Reviews math work everyday or almost everyday	-7.99***	-8.11***
Solve math problems rarely	-0.89	-0.88
Solve math problems less than once a week	-1.31	-1.21
Solve math problems once or twice a week	1.33	1.42
Solve math problems everyday or almost everyday	-1.37	-1.41
Graphing rarely	0.91	0.74
Graphing less than once a week	-1.18	-1.48
Graphing once or twice a week	2.48	2.22
Graphing everyday or almost everyday	0.26	0.24
Math drills rarely	-1.66	-1.68
Math drills less than once a week	-0.49	-0.51
Math drills once or twice a week	1.05	0.88
Math drills everyday or almost everyday	-2.06	-1.90
Analyze data rarely	1.62	1.55
Analyze data less than once a week	-0.05	-0.14
Analyze data once or twice a week	0.10	0.09
Analyze data everyday or almost everyday	2.21	2.17
Apply learning rarely	1.79	1.80
Apply learning less than once a week	4.16*	4.42*
Apply learning once or twice a week	2.49	2.52
Apply learning everyday or almost everyday	1.92	1.89
Instruct one-on-one rarely	1.72	1.68

Table H1 (continued)

	Level 1	Level 1 & Level 2
Instruct one-on-one less than once a week	1.05	1.02
Instruct one-on-one once or twice a week	-0.48	-0.52
Instruct one-on-one everyday or almost everyday	1.43	1.42
Show new topics rarely	0.31	0.36
Show new topics less than once a week	-1.14	-1.11
Show new topics once or twice a week	-2.95	-2.92
Show new topics everyday or almost everyday	1.51	1.75
Home computer use	1.09***	1.09**
Professional development		
Training in basic computer skills	-0.22	-0.16
Training in software applications	1.10	1.01
Training in use of Internet	-0.01	0.23
Training in other technology	-0.57	-0.64
Training in integrating technology	0.21	0.21
Advanced training	-0.11	-0.06
Student demographics		
American Indian	-3.06**	-2.73**
Asian	2.28**	2.34**
Black	-4.87***	-4.31***
Hispanic	-3.92***	-3.51***
Multiracial	-1.27*	-1.21*
Female	-0.19	-0.10
Socio-economic status	3.40***	3.18***
Teacher demographics		
Teacher’s years of experience	0.13***	0.13***
Teacher’s age	-0.04	-0.04
Gender interactions		
Female * Frequency of computer use	0.20	0.18
Female * Reviews math work rarely	-1.20	-1.00
Female * Reviews math work less than once a week	2.65	2.73
Female * Reviews math work once or twice a week	1.48	1.15
Female * Reviews math work everyday or almost everyday	6.59*	6.69*
Female * Solve math problems rarely	0.04	0.13
Female * Solve math problems less than once a week	3.04	2.87

Table H1 (continued)

	Level 1	Level 1 & Level 2
Female * Solve math problems once or twice a week	-3.88	-3.92
Female * Solve math problems everyday or almost everyday	-2.50	-2.17
Female * Graphing rarely	1.20	1.28
Female * Graphing less than once a week	5.20*	5.38*
Female * Graphing once or twice a week	-0.47	-0.24
Female * Graphing everyday or almost everyday	2.29	2.21
Female * Math drills rarely	0.46	0.24
Female * Math drills less than once a week	0.33	0.35
Female * Math drills once or twice a week	-2.14	-1.91
Female * Math drills everyday or almost everyday	0.92	-.60
Female * Analyze data rarely	-3.66	-3.59
Female * Analyze data less than once a week	-1.48	-1.39
Female * Analyze data once or twice a week	-0.54	-0.47
Female * Analyze data everyday or almost everyday	-5.85	-5.86
Female * Apply learning rarely	1.31	1.40
Female * Apply learning less than once a week	-1.77	-2.17
Female * Apply learning once or twice a week	-0.39	-0.34
Female * Apply learning everyday or almost everyday	0.91	1.04
Female * Instruct one-on-one rarely	-2.45	-2.41
Female * Instruct one-on-one less than once a week	-2.72	-2.54
Female * Instruct one-on-one once or twice a week	-0.73	-0.83
Female * Instruct one-on-one everyday or almost everyday	-3.62	-3.27
Female * Show new topics rarely	0.23	0.04
Female * Show new topics less than once a week	3.81	3.64
Female * Show new topics once or twice a week	6.83*	6.67*
Female * Show new topics everyday or almost everyday	0.53	0.46
Female * Training in basic computer skills	0.03	0.08
Female * Training in software applications	-1.37	-1.36
Female * Training in use of Internet	1.51	1.43
Female * Training in other technology	0.41	0.36
Female * Training in integrating technology	0.16	0.20
Female * Advanced training	0.44	0.51
Female * Home computer use	-0.52**	-0.53

Table H1 (continued)

	Level 1	Level 1 & Level 2
Level 2		
Catholic		0.74
Non-Catholic private		0.43
Urban		-0.32
Rural		0.09
FRL 0 to 5		1.91
FRL 6 to 10		1.60
FRL 11 to 20		1.14
FRL 21 to 30		-0.35
FRL 51 to 75		-1.07
FRL 76 to 100		-1.88
Random effect	Variance component	Variance component
Intercept (variance between schools)	57.27	57.18
Level 1 (variance within schools)	7.77	6.74
Intraclass Correlation	.12	.11
Variance in achievement between schools (%) explained		68.11
Variance in achievement within schools (%) explained	21.36	21.49

* $p < .05$; ** $p < .01$; *** $p < .001$

Appendix I

Composite Multilevel Model Analysis

Table I1

Model Comparison, Level 1 Only and Level 1 and 2, Weighted and Non-imputed

	Level 1	Level 1 & Level 2
Level 1		
Standardized math score	51.57	50.46
Computer use		
Frequency of computer use	-1.24***	-1.21***
Frequency of Computer Applications	-0.09	-0.12
Home Computer Use	1.13***	1.12***
Professional development		
Training in Basic Computer Skills	-0.45	-0.38
Training in Software Applications	0.93	0.80
Training in use of Internet	0.26	0.49
Training in Other Technology	-0.34	-0.43
Training in Integrating Technology	-0.10	-0.04
Advanced Training	-0.26	-0.21
Student demographics		
American Indian	-3.22***	-2.88***
Asian	2.20**	2.30**
Black	-5.26***	-4.60***
Hispanic	-4.16***	-3.72***
Multiracial	-1.43**	-1.34*
Female	-0.27	-0.25
Socio-economic Status	3.35***	3.17***
Teacher demographics		
Teacher's Years of Experience	0.12**	0.12**
Teacher's Age	-0.04	-0.04
Gender interactions		
Female * Frequency of Computer Use	0.05	0.03
Female * Frequency of Computer Applications	-0.07	-0.03
Female * Training in Basic Computer Skills	0.42	0.46
Female * Training in Software Applications	-0.99	-0.96

Table I1 (continued)

	Level 1	Level 1 & Level 2
Female * Training in use of Internet	1.12	1.03
Female * Training in Other Technology	0.10	0.07
Female * Training in Integrating Technology	0.44	0.43
Female * Advanced Training	0.63	0.68
Female * Home Computer Use	-0.54**	-0.55**
Level 2		
Catholic		0.78
Other Private		0.30
Urban		-0.32
Rural		0.24
FRL 0 to 5		2.01**
FRL 6 to 10		1.78*
FRL 11 to 20		1.25
FRL 21 to 30		-0.23
FRL 51 to 75		-1.09
FRL 76 to 100		-2.28**
	Variance Component	Variance Component
Intercept (variance between schools)	58.26	58.17
Level 1 (variance within schools)	8.35	7.13
Intraclass Correlation	.13	.11
Variance in achievement between schools (%) explained		66.25
Variance in achievement within schools (%) explained	20.02	20.14

* $p < .05$; ** $p < .01$; *** $p < .001$