THE EFFECT OF INTRODUCING COMPUTERS INTO AN INTRODUCTORY PHYSICS PROBLEM-SOLVING LABORATORY

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This is to certify that I have examined this copy of a doctoral thesis by

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And have found that it is complete and satisfactory in all respects, and that any and all revisions required by the final examining committee have been made.

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DEDICATION

This dissertation is dedicated to my husband Kelly McCullough. You are a part of every page, every thought. *Quaheystamaha.*

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ABSTRACT

Computers are appearing in every type of classroom across the country. Yet they often appear without benefit of studying their effects. The research that is available on computer use in classrooms has found mixed results, and often ignores the theoretical and instructional contexts of the computer and the classroom. The University of Minnesota's physics department employs a cooperative-group problem solving pedagogy in its calculus-based introductory physics course. This study examines the effects of introducing a computerized data-acquisition and analysis tool into this pedagogy as a problem-solving tool for students to use in laboratory. To determine the effects of the computer tool, two quasi-experimental treatment groups were selected. The quasi-experimental group used a computer tool to collect and analyze data in the laboratory, while the control group used traditional non-computer equipment. The curriculum was kept as similar as possible for the two groups. The groups were examined for effects on performance on conceptual tests and grades, attitudes towards the laboratory and the laboratory tools, and behaviors within cooperative groups. Possible interactions with gender were also examined. Few differences were found between the control and quasi-experimental groups. The control group received slightly higher scores on one conceptual test. The quasi-experimental group had slightly more positive attitudes towards using the computer tool than their counterparts had towards the traditional tools. The quasi-experimental group perceived that they spoke more frequently about physics misunderstandings, while the control group felt that they discussed equipment difficulties more often. This difference interacted with gender, with the men in the control group more likely to discuss equipment difficulties than any other group. Overall, the differences between the control and quasi-experimental groups were minimal.

TABLE OF CONTENTS

LIST OF TABLES

Chapter 4

Chapter 1 Introduction

Rapid technological change is an inevitable aspect of modern life. Each new year brings advances in a whole host of areas from the kitchen to the car to the DNA that makes up our beings. This is as true for education as it is for every other aspect of our lives. All over the country, in classrooms of every level, teachers are working to take advantage of the opportunities that these advances in technology afford. There are constant pressures from administrations, from the government, from parents, and from the students themselves, to adopt the newest and latest in technology. Computers are the overwhelmingly dominant example of this technological change in the way we do things, especially in the sciences. Science classrooms in general, and physics classrooms in particular, are rushing to embrace the computer as an educational tool. This is a reasonable adaptation for a field that sees computers used in every aspect of its application. The computer can be found in every physics research lab as an integral part of the lab.

In order to better serve their students many college physics professors are trying to bring computers into their introductory physics courses. This is especially true for laboratories. This is an admirable effort and it raises important questions. How should these computers be used in laboratories? What is the best application of computer technology for a given classroom environment? How can computers best serve the needs of laboratories with different goals and levels of integration with introductory physics courses? It seems unlikely that what works in one setting will work the same way in another setting.

Background

Many researchers have studied the effects of using computers in various components of classrooms. In general, the research has looked at the effects of computer use in four areas: achievement, attitudes, group and individual behavior, and gender interactions. Each of these areas is summarized below.

Achievement:

Several studies have focused on how the use of the computer affects students' achievement (Brasell, 1987; Brungardt & Zollman, 1995). Typically these studies define achievement very narrowly, for example, graphing skills or a single kinematics concept. Often achievement is defined as the ability to perform the same task or skill which the computer was used to learn. Very few studies look at achievement in any broader sense, such as overall lab performance or overall course grades (Tsai, Bethel, & Huntsberger, 1999; Leonard, 1992). A few meta-analyses have examined the literature on how computers affect achievement (usually defined narrowly), and found that there is no clear answer on whether or not computers in the classroom can enhance student achievement (Kulik & Kulik, 1980, 1986). In college physics, the use of microcomputer-based labs (MBLs) has had mixed results for student performance on certain skills and concepts (Beichner, 1996).

Attitudes:

One of the recurring advantages attributed to using computers in the classroom is that of more positive student attitudes (Brasell, 1987; Brungardt & Zollman, 1995). Using computers in a classroom is believed to lead to more positive attitudes in students, because computers can do so many new things so quickly, so carefully, and because many students prefer using computers. There is little research, however, to support such claims. This feeling that computers engender more positive attitudes seems to stem more from teachers' personal experiences than from actual research on the topic (for example, Brasell, 1987 and Cordes, 1990). The limited research available suggests that computers can lead to more positive attitudes in some groups of students (males, younger students).

Group Behavior:

There is a substantial amount of literature on groups and computers. A few of these studies have examined how students interact in groups with a computer (Wizer, 1995), and what sort of groupings work best with computers (Howe, Tolmie, Anderson, and MacKenzie, 1992). Groups which discuss problems and try to resolve conflicts work better than groups which do not. Sharing use of the keyboard and helping explain concepts to each other also works well. Most of the research, however, compares how computer use varies when students work individually versus working cooperatively (e.g., Jackson, Fletcher, and Messer, 1992; and Carnes, 1985). In general, computer use in groups can lead to higher achievement than computer use by individuals. In these studies, computer use is a constant, and group versus individual work is the variable. There are no investigations in college science of how group behavior varies with and without a computer—where the variable is use of computers and some groups use computers and some do not.

Gender Interactions:

The last issue of interest is how computer use interacts with gender. There is an unspoken assumption that computers are “boys’ things,” and that girls are less interested or less likely to work on computers. This could have serious consequences if using the computer affects achievement and learning. The literature on this topic supports the general sentiment that males like the computer better than females, and males do better on tasks using the computer (for example, Busch, 1996 and Barbieri & Light, 1992).

Context of this Study

In introductory college physics courses for scientists and engineers, a common course goal is to have students learn physics through solving physics problems. The most common course structure has three components: lecture, recitation, and laboratory. The instructor typically solves some example problems in lecture, the students practice solving problems on homework, and perhaps in a recitation section as well. The laboratory component of the course is often separate from the lecture, and involves students verifying physical laws through data collection and analysis. This approach is very traditional and many courses throughout the country have used this approach for years.

Over the past ten years, several reform movements have been started with the goal of improving introductory physics courses for scientists and engineers. Most of these reforms are designed for a single component of a course: lecture, lab, or recitation. They are, in a sense, modular. The majority of the reforms have developmental underpinnings—their goal is to have students move from a less scientific conceptual understanding of physics to a more scientific one. For example, Interactive Lecture Demonstrations (Thornton & Sokoloff, 1997) use carefully chosen demonstrations and probing questions to help students learn physics concepts. Tutorials in Introductory Physics (McDermott, Shaffer, and the Physics Education Group at the University of Washington, 1998) are designed to replace traditional recitations. Tutorials consist of short sequences of activities in which students predict, observe, and explain different phenomena. The tutorials are specifically designed to help students overcome their misconceptions and develop a more scientific understanding. Microcomputer-based laboratories (Thornton, 1990) take advantage of multiple sensors and probes connected to graphing software to help students learn physics.

Only two reform movements take a holistic approach to physics teaching and learning. Workshop Physics (Laws, 1997) is an activity-based complete curriculum for small introductory physics courses. Instead of the typical three-component course structure, students in a Workshop Physics course work in groups on activities, with whole-class discussions interspersed throughout the class period. There are no lectures or separate labs or recitations. An instructor choosing to adopt this curriculum must take the whole package; they cannot adopt only a piece of it to use in one component of their course.

The second reform movement to take a holistic approach is Cooperative Group Problem Solving (CGPS) (Heller & Hollabaugh, 1992; and Heller, Keith, & Anderson, 1992). This curriculum / instructional approach has been developed by members of the Physics Education Research and Development Group at the University of Minnesota[1], through many years of ongoing research supported by National Science Foundation (NSF) and Fund for the Improvement of Post-Secondary Education (FIPSE) grants.

In Cooperative Group Problem Solving (CGPS), the lecture, the laboratory, and the recitation are all equally important course components designed to help students reach the goal of improving their problem-solving skills. During lecture, the professor explicitly models how to use physics concepts and principles to solve problems. Students are then coached in problem solving during labs and recitations. In both recitation and lab they work in the same groups to solve context-rich problems, so that they have access to peer

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[1] Members include Dr. Ken Heller, assistant chair of the Physics Department, Dr. Pat Heller, professor in Curriculum & Instruction, Tom Foster, Laura McCullough, and other current and former physics and science education graduate students.

Table 1.1

Sample Recitation and Laboratory Problems

Sample Recitation Problem
You are taking care of two small children, Sarah and Rachel, who are twins. On a nice cold, clear day you decide to take them ice skating on Lake of the Isles. To travel across the frozen lake you have Sarah hold your hand and Rachel's hand. The three of you form a straight line as you skate, and the two children just glide. Sarah must reach up at an angle of 60 degrees to grasp your hand, but she grabs Rachel's hand horizontally. Since the children are twins, they are the same height and the same weight, 50 lbs. To get started you accelerate at 2.0 m/s^2. You are concerned about the force on the children's arms which might cause shoulder damage. So you calculate the force Sarah exerts on Rachel's arm, and the force you exert on Sarah's other arm. You assume that the frictional forces of the ice surface on the skates are negligible.
Sample Laboratory Problem
You are volunteering for the city's children summer program. One suggested activity is for the children to build and race model cars. To ensure that each car starts the race with the same velocity, the activity recommends a special launcher be built. The launcher uses a string attached to the car at one end and, after passing over a pulley, the other end of the string is tied to a 100 gm mass. The mass is allowed to fall half of a meter to launch a car down the track. You are not sure if this design will launch every car with the same velocity, so you decide to test the design yourself.

coaching as well as to coaching from their instructor (a teaching assistant). Table 1.1 gives an example of both a recitation problem and a laboratory problem.

The laboratory in CGPS is unique in that it has the same goal as the recitation: problem-solving. Students in lab perform similar tasks to those in recitation, with the addition that in the laboratory the students check their problem solutions with experiments in the real world. A CGPS course is like a jigsaw puzzle—every piece is needed to create the whole picture, and each piece must fit with those surrounding it.

Rationale

The present study is part of the ongoing research and development of the CGPS curriculum. The problem-solving labs, as part of the Cooperative Group Problem Solving course, have been working very well. In order to keep the laboratories up to date and in keeping with the needs of the students served by the labs, the Physics Education Research and Development Group received a grant to investigate the effect of adding computer data collection and analysis tools to the problem-solving laboratories. As stated above, the research literature on the effects of introducing computers to courses shows that results on achievement, attitude and group behaviors are either not thoroughly studied or have inconclusive results. And in nearly every research study examined, the authors failed to mention in what context the study took place. Most studies seemed isolated from any larger course goals or theoretical frameworks, focusing instead on more modular applications of computers to courses, and to labs in particular. This review of the possible effects of computers was a cause for concern, since the Group did not want to make any changes to the course that would have deleterious effects on students. Because of this, the investigation of the effects of adding computer tools to problem-solving laboratories was designed in two phases.

In phase one, the only change made to the course was to replace some of the data collection and analysis tools used in the laboratory with new, carefully designed computer tools. Only a few sections of the course would be used to pilot test the first stage of the design. The effects of this change would be studied, and if the results suggested that simply replacing the tools did not detract from the overall course goals, then phase two could begin. In phase two the curriculum would be adapted to take advantage of the new computer tools. New laboratory problems would be written and tested to maximize the power of the new computer tools. If, however, the results of phase one showed that the computer tool was causing serious problems in the laboratories, then phase two would be postponed and the computer tool would be redesigned and pilot tested again.

This study focuses only on phase one—investigating the effects of replacing some of the laboratory tools with a computer tool. The concern was that students would focus on the computer itself instead of the physics they were supposed to be learning by using the computer. Because of the problem-solving nature of the lab, the computer tools needed to elicit specific decisions from the students. None of the commercially available software fit these requirements, so the Group chose to design their own software. For this study, the computer data collection and analysis tool required using a video camera to capture a movie or video of the desired motion.

The video is sent to the computer program, where students make predictions about X and Y motion, choose axes and reference lengths, and take position data from the video. Students analyze the video data using the computer program, and then print out their results.

This computer tool, hereafter called VideoTool, was used in the first quarter of the introductory physics course for scientists and engineers at the University of Minnesota.

Research Questions

1. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change students' achievement?
    a. Do students in problem-solving laboratories with VideoTool (experimental treatment) gain equally well as students in problem-solving laboratories with traditional tools (control treatment) on a test of understanding kinematics?
    b. Do students in the two treatments gain equally on a test of understanding force?
    c. Do students in the two treatments do equally well on overall course grades?
2. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change students' attitudes?
    a. Do students in problem-solving laboratories with VideoTool (experimental treatment) have the same overall attitude towards the

course as students in problem-solving laboratories with traditional tools (control treatment)?

   b. Do students in the two treatments have the same attitude towards using the specific computer or non-computer tools used in the laboratory?

3. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change how groups solve the laboratory problem?
   a. Do groups in problem-solving laboratories with VideoTool (experimental treatment) spend the same amount of time in each part of the laboratory as groups in problem-solving laboratories with traditional tools (control treatment)?
   b. Do groups in the two treatments talk about the same things while solving the laboratory problems?
   c. Do students in the two treatments perceive their group functioning differently?
4. Are there any gender-treatment interactions?
   a. Is there a gender-treatment interaction for the three measures of achievement?
   b. Is there a gender-treatment interaction for students' attitudes towards the overall course and towards the particular laboratory tools?
   c. Is there a gender-treatment interaction for how students perceive their group functioning?

Research Design

Since the purpose of this study was to investigate the effects of using a computer tool in the laboratory, it was important to keep every other variable as close to equivalent as possible between the experimental and control groups. The introductory physics course for scientists and engineers at the University of Minnesota typically serves 800-1000 students a year. Five different lecturers are assigned three to eight teaching assistants, who teach the recitations and labs. Three of these five lecture sections were used in the study. To control for possible instructor effects, the computer tool was added to 14 randomly selected laboratory sections of the course, divided among the three lecture sections. The other 13 laboratories of the three lectures used the traditional non-computer tools. Since teaching assistants are randomly assigned to sections, no extra control for teaching assistant instructor effect was required. So both the control and the experimental groups had the same lectures, the same recitations, and the same laboratory problems. The only difference was that the experimental treatment group used a computer tool to solve the laboratory problems, while the control group used the traditional data collection and analysis tools (spark tape and Polaroid cameras).

Because it was not possible to randomly assign individual students to computer-use or non-computer-use, the randomization was made by laboratory section. Students did not know if they were registering for an experimental section or a control section. They found out at their first laboratory session. Campbell and Stanley (1963) refer to this design as a non-equivalent control group design (Design 10). Because the individuals cannot be randomly assigned, it is not a true experimental design. But the more similarity between the two groups (as can be measured on pretests) the better this type of control becomes.

To answer the four research questions, several instruments were used to measure different aspects of student performance in the course: achievement, attitudes, and group behaviors.

Achievement:

Three measures were used to assess the achievement of the students. The two groups were given the same two conceptual tests as pretests and as post-tests. Course grades were also examined as a measure of overall achievement.

Attitudes:

A survey asking about their attitudes towards the course and the laboratory tools was given to both groups at the end of the term.

Group Behaviors:

To answer the third question about how groups solve the lab problem, a deeper look was needed. Six observers were trained to make structured time observations of groups solving the lab problem. Groups from both the experimental and control treatments were observed. The observers took data on what part of the lab the group was in, what the group was talking about, and who talked to whom. A second source of information on group behaviors was a set of nine questions about group functioning given to students at the end of the term.

Gender:

Information about the student's gender was collected with each of these measures, so that any possible gender effects could be determined.

This non-equivalent control group design is made more powerful when the two groups can be compared on different pretest measures and found to be similar. By using many different pretest measures, and by using multiple measures for assessing student achievement, attitude, and group behaviors, any claims made about the equality or inequality of the two treatments is strengthened. This design also uses several different methods of collecting data, which will contribute to current research in the field, since most research to date has been very focused in scope and method.

Significance and Limitations

This study advances the research field of computers in the classroom in several ways. First, it looks at overall achievement of students instead of looking only at one particular skill or concept. Second, this study asks students themselves about how they feel toward using the computer tool. Third, it will look carefully at how the use of the computer tool affects the way that cooperative groups work. This study will offer new insights in several different areas of research in computers in education. However, because the context of the study is unique, there is limited generalizability in two ways.

The course examined uses a particular pedagogy which is not in wide use in introductory college physics teaching. This pedagogy takes a holistic view of the course and also uses an instructional paradigm of cognitive apprenticeship. Because of this unusual pedagogy, in which the laboratory is an integrated part of the course, this study looked at overall effects instead of effects only in the laboratory. Therefore these results are not generalizable to courses where the laboratory is not integrated into the entire course.

This study also examined a very specific computer tool, which was designed to match the pedagogy of the course. Other computer tools have different purposes, and may not have similar effects on achievement and attitudes. One cannot generalize that using this tool in another course which does not follow this pedagogy would have the same effects.

Overview of the Dissertation

The following list provides a brief guide of the remaining chapters of this dissertation:

Chapter 2 Review of the Literature

This chapter provides a review of research relevant to the purpose of this study.

Chapter 3 Methods

This chapter presents a detailed description of the research design and methods employed in this study.

Chapter 4 Results

This chapter presents the results of the study.

Chapter 5 Conclusions

This chapter reports on the conclusions drawn from the experimental results of the study and discusses the implications for further work.

Bibliography

Appendices

Chapter 2 A Review of the Literature

Overview

This study seeks to understand how the addition of a computer tool to a problem-solving laboratory affects students in several dimensions: their achievement, their attitudes, and their actions in the lab. As technology has been introduced in classrooms over the last twenty years, research on the effects of technology has also been necessary. Much of the research on the use of computers has focused on the achievement of students. Other research has looked at different aspects of using computers: group work, gender, attitudes, and problem solving, among others. Yet this field of research is characterized by a technological approach rather than a pedagogical approach. Few studies mention the larger pedagogical context of the class being studied, or the pedagogical goals for using the computers. In the first phase of this study, the computerized data collection and analysis tool (VideoTool) was added to a very structured pedagogy, and the tool was carefully designed to aid that pedagogy and the instructional goals of the course and the laboratory.

In this chapter I present research and discussion on pedagogical approaches and uses of computers. The chapter starts with rationales for using computers, then moves on to what is known about adding computers to classrooms. Because this study takes place in a specific instructional context, I will also discuss three different instructional paradigms and how laboratories and computers relate to these paradigms.

Why use computers?

Computers are being introduced into classrooms of every size, shape, and color all over the world. Why is there such a rush to incorporate technology when the research on its effects is still in its infancy? For many people, the *a priori* advantages to using computers in the classroom outweigh any perceived *a priori* disadvantages. What are some of these advantages that people have attributed to using computers in the classroom?

At the Conference on Computers in Physics Instruction in Raleigh, NC in 1988, many participants summed up arguments for adding computers to physics courses. Johnston (1990) suggests that computers have the following advantages:

(1) Interactivity invites students to become active learners.

(2) Interactions are planned, using what is known about students' misconceptions to guide students to better models.

(3) Computers are infinitely patient and able to repeat interactions many times with many students.

(4) The computer is non-judgmental and interactions can be kept private, giving the student more freedom to answer honestly without social consequences.

(5) Computers can be used in a variety of ways, and each interaction can be personalized to the user.

The developers of Tools for Scientific Thinking (Thornton, 1990) suggest that computers can easily manipulate and transfer between different modes of representation.

Computers also allow students to save data for later analysis, and allow for easy sharing of data within a class. Nordling (1990) suggests that one computer can replace many conventional measuring devices such as oscilloscopes, timers, multimeters, thermometers, etc. The computer allows for a great deal of data to be collected, and it often can be gathered faster and with fewer errors. The computer can make analysis and graphing easier and faster. With quicker data gathering and analysis, a given experiment can easily be repeated during a lab period, to verify results or to make minor modifications to the experiment. Ager (1990) sees computers as a route to individualized instruction, providing greater instructional access to students, and special instruction to those students with special needs. Ager also suggests that if computers can do some of the stable tasks of teaching, teachers can reallocate their time to more important parts of the process. Computers also can provide standardized instruction across classrooms and instructors.

Better learning and/or more efficient learning are areas where it is hoped that the inclusion of computers in the classroom will lead to the biggest gains. Most research on computers in education focuses on these types of questions. Yet few people mention the larger instructional paradigm when talking about computers. Most pedagogies found in the research are simply modules with a certain instructional approach, which also use computers. Rarely do researchers mention connecting computers to the larger course design. Instead, "Experience shows that many technology approaches are based on technology instead of pedagogy. This is a serious error." (Bork, 1990, p. 34).

Given this underlying problem in current research on adding computers to a classroom, the Physics Education Research and Development Group chose a two-phase pedagogical approach to adding computers rather than the technological approach. VideoTool was carefully implemented as a complement to the overall pedagogy of the course, and the particular pedagogy of the laboratories in which it would be used.

In this study, VideoTool was added to the laboratories for several reasons. From the underlying pedagogical point of view, computers are part of the proper context for learning physics. Every physics research laboratory has several computers; some branches of theoretical physics are only possible because of the power of supercomputers. As discussed below, part of teaching physics using a cognitive apprenticeship paradigm is teaching in an appropriate context. Students coming into this class would reasonably expect to see computers. Many high school physics classrooms use computers, and many of the other science and engineering courses these students take use computers. Technology is inveigling its way into every aspect of education.

The developers also envisioned that using computers could allow students to take data more quickly and with fewer errors. Computers are relatively low maintenance equipment when compared with air tracks and spark timers, and they take up no storage space since they are always in the lab. Computers can reduce the time taken in analysis of data, since the computer is able to quickly perform tedious calculations previously done on calculator or by hand.

These reasons got computers into the classroom, however, the approach was designed in two phases to be sure that no pedagogical value would be lost with the addition of the computer tool. Of all the reasons given for adding computers to a class, the pedagogical ones may be the most important.

What we know about adding computers

Since the first personal computers appeared in the late 1970s, teachers have thought of ways to use these devices in their classrooms. Many articles have been written on different ways to use computers in the classroom. This section will review what people have learned about using computers in the classroom. Several different aspects of computer use will be looked at: computers and achievement, problem solving, attitudes, group work, and gender.

Computers and achievement:

Like television in an earlier era, computers have been hailed as a panacea for all educational woes. Unfortunately, they have not always lived up to this promise. Most of the research on educational computer use has focused on the issue of better learning as evidenced by better achievement on various measures. Several meta-analyses have been performed on this literature. Kulik and Kulik (1986) reported, in a meta-analysis of computer-based education (CBE) in colleges, an overall positive effect for CBE. In the hard sciences, the effects are less clear, especially when you examine the different ways the computer is used in the classroom.

Early approaches to educational technology, and computers in particular, evolved from a behaviorist psychology (Saettler, 1990; Koschmann, 1996). Behaviorists believe that learning happens in response to stimuli, so computers were used in drill-and-practice types of implementations. According to behaviorist theory, the computer can produce more questions more quickly, which means more efficient learning, which means more effective learning.

Educational technology approaches have since shifted to a more cognitive paradigm (Saettler, 1990; Strittmatter, 1990). This cognitive approach looks more towards students' individual learning styles and needs (Weisgerber, 1971). For this theory, the computer can be used to help individualize instruction (Ager, 1990), which will lead to better student learning.

When one examines the research in physics education, most studies involve micro-computer based labs (MBLs). Beginning with Brasell's study in 1987, several researchers have found that using MBLs can increase students' understanding of kinematics graphs (Linn, Layman, & Nachmias, 1987; Mokros & Tinker, 1987; Thornton, 1990). Others have found no differences in achievement between those in computer-based laboratories and those in traditional laboratories (Cordes, 1990; Leonard, 1992). In a report on contexts which affect math and science literacy for Minnesota 12th graders, "computer use was not clearly related to higher math and science literacy scores" (SciMathMN, 1999, p.10). There seems to be no clear consensus on how using computers affects achievement in science. Despite this lack of consensus on achievement results, several researchers have discovered the same implementation principle that Beichner (1996) has: " Teachers must thoroughly integrate software into their instruction and not just tack it on." (p.1276)

One cause for concern is voiced by Nakhleh (1994) in a review of the research on MBLs: "Many of these studies allowed a very short time for treatment, and these treatments were often specially designed modules which bore little relationship to the total curriculum or were treatments experienced by individuals in a clinical setting" (p.378). Indeed, most research does not include any sense of the larger setting in which the research took place.

This study takes into account the larger environment of which the computers and the laboratories are a part. How does the addition of the computers in a carefully designed manner affect overall achievement of the students in the course? By looking at this question, this study will advance knowledge of how computers affect the entire classroom experience. Based on the previous research on computers and achievement, no increase in achievement is expected; instead one would hope for no decrease in achievement. The addition of the computer tool to the laboratory was not optimized for achievement. The tool was added in a fashion so as to disturb as little as possible of the successful theory-based pedagogy that was already in place. The underlying question is whether the computer tool itself would cause any decrease in achievement.

Computers and problem solving:

One of the attributes ascribed to computers is that they can teach students problem-solving. Most of this research has focused on using computer programming to achieve this goal. Casey (1997) suggests that "since many of the skills required for successful programming are similar to those required for effective problem-solving, computer programming…provides a fertile field for developing and practicing problem-solving skills" (p. 41). Mathematics is another area where there is a great deal of research on problem solving with computers. Wright (1997) suggests ways to use the computer to make advanced mathematics problems easier to understand, using a numerical approach to solve them. Some of the issues surrounding integrating technology into a computer classroom were discussed by Pokay and Tayeh (1997) and Verzoni (1997). Yet these research areas do not get at the core of how the computer is used in *this* study—as a tool to solve physics problems. In a study closer in focus to this one, Lajoie and Lesgold (1989) used the computer in a cognitive apprenticeship environment to teach troubleshooting / problem-solving skills to Air Force technicians. They found that the computer was extremely successful in improving the technicians' troubleshooting abilities.

In physics, several groups have undertaken the goal of using the computer as a personal tutor to teach problem solving. Chabay (1990) discusses how the research on human learning can help in the development of competent computer tutors. Reif and Scott (1999) have used computers as tutors to help students learn how to solve physics problems. But again, these problem-solving computer tutors do not match the use of the computer in this study. There is very little research on how the addition of the computer as a problem-solving tool affects students in the classroom. The lack of mention of the larger instructional context in most of these studies is also disturbing. The majority of this research is focused solely on that part of the classroom which uses the computer, and the results from that part of the classroom. In contrast, this dissertation study will focus on the effects on the entire class—overall achievement and attitudes, as well as the effects on the laboratory.

Computers and attitudes:

One of the possible advantages of using computers in the classroom is a better student attitude towards the course (or the laboratory, or science). Over the years, many different researchers have suggested that computers can affect attitudes (Bork, 1990; Dykstra, 1990; Brasell, 1987; Cordes, 1990). Their reasons have varied. Some authors have argued that since students are familiar with computers outside of school, and students typically view computers positively or as fun toys, these positive attitudes will transfer into the classroom. Others argue that since computers can accomplish tasks more quickly and with fewer errors, students will prefer the work on computers and feel more positive about using them in their classes. Another argument is that computers make a class more interactive, thereby motivating the students, and inducing more positive attitudes. With this array of arguments, many teachers and researchers have *assumed* that adding computers leads to more positive attitudes in students.

There is little research on attitudes, however. In an early general meta-analysis of the effects of computer-based education, only three studies could be found (Berger, Lu, Belzer, & Voss, 1994). In physics education, some of the research on microcomputer-based labs has suggested that using computers in the classroom is a possible advantage, at least in terms of motivating students. Yet most of the data is based on the general feelings of the teachers rather than research. Brasell (1987) suggests that "real-time graphing of data appears to be a key feature for both cognition and motivation." Brungardt and Zollman (1995) also found real-time graphing to be motivating to students. Students using temperature probes connected to computers enjoyed the work and suggested that they be used more (Cordes, 1990). Students generally seem pleased with using MBLs, according to Thornton (1990) and Griffin (1990). One study actually examined some of the underlying causes of attitudes towards computers. Cordes et. al. (1997) studied the effects of age and gender on computer attitudes, and found that younger students and male students have more positive attitudes towards computers. The gender effect, however, disappeared when prior computer use was controlled for.

It is difficult to tell from this research how a computer tool affects the attitudes of the students using it. This study will explicitly ask students about their attitudes towards both the laboratory and the course, using a post-course survey. By asking every student about their attitudes towards using the computer tool or the traditional equipment, it will be possible to confidently determine the effects of adding a computer tool to this classroom.

Computers and group work:

As the number of classrooms using cooperative group work grows, so does the number of classrooms using cooperative group work and computers.

The field of computer-supported collaborative work has matured rapidly in the last decade. A symposia in 1992 on this topic produced an entire volume of papers (Koschmann, 1996). There are several theoretical perspectives underlying this field of study. The first is that of social development (Vygotsky, 1962), which suggests that all learning is social in nature, which leads directly into working in groups. A related theory is social constructivism (Cobb, 1994), which also includes the idea that knowledge is *constructed* by the learners working together. Another important theory is that of situated learning (Lave, 1990), in which the context of learning interacts with the learner. All of these combine to suggest that the computer can be a powerful agent of change when combined with collaborative learning.

Denning and Smith (1997) provide a summary of many of the available software programs which are designed to support cooperative learning. Jehng (1997) and others have suggested that the nature of a computer learning environment is likely to change the nature of the psycho-social behaviors during collaborative work. It is valuable to study the effects of adding a computer to a collaborative environment. There are an increasing number of studies looking at this issue (Hooper, 1992; Johnson, Johnson, and Stanne, 1986; Mevarech & Light, 1992; Mevarech, 1993; and Repman, 1993).

A common topic in this area is the effect of group work on computers versus individual work on computers. Jackson, Fletcher, and Messer (1992) and Carnes (1985) found that students show higher performance on achievement tasks when they worked in groups as opposed to working individually. Jehng (1997) found that group work promotes better computer program building than individual work. Others have focused not on comparisons, but specifically on group work with computers to determine what factors affect achievement and concept construction. Tao and Gunstone (1997) determined that students who were cognitively engaged in their tasks, and were prepared to reflect on their conceptions, experienced conceptual change. Kumpulainen and Mutanen (1998) found, however, that collaborative work on the computer did not necessarily lead students to learn science collaboratively.

Another approach taken has focused on the nature of the group and actions taken by the group. Howe, Tolmie, Anderson, and MacKenzie (1992) found that heterogeneous groupings which lead to peer conflict and hypothesis testing result in greater achievement on a problem-solving task. The ability to resolve conflicts within groups can also lead to enhanced achievement (Hoffman, 1997). Mutual keyboard usage and giving explanations led to increased achievement for middle school math students (Wizer, 1995). Kelly and Crawford (1996) carefully examined students' interactions in groups and found 5 ways that the computer and students interact:

(1) The computer is an ally for a student to make a case.

(2) The computer acts to help construct meaning in a group by providing evidence and phenomena.

(3) The computer can exhibit crucial information.

(4) The computer can elicit student responses.

(5) The computer presents students with observations discrepant with their expectations.

There is a good deal of literature on computers and group work. Yet of all the studies mentioned above, not one mentioned the instructional paradigm of the classroom being studied, or how the computers related to the larger instructional goals of the course. There also appear to be no studies which compare cooperative groups with and without computers. The comparison studies have all focused on cooperative versus individual work—computer use is kept constant while some students work individually and others work cooperatively. In contrast, this study keeps cooperative grouping constant and looks at the effect of having some groups use a computer tool while others do not. What is clear is that there is a need to study this issue in more depth. How does the use of computers affect the larger classroom environment, in this case, one of cognitive apprenticeship? How do the computers change the interactions among groups? This study will broaden the research literature on group work and computers.

Computers and gender:

When dealing with the domains of science, the issue of gender is often relevant to study. In physics particularly, women comprise a very low percentage of the number of degrees granted: 19% of bachelor's degrees, 18% of master's degrees and 12% of Ph.D.s in physics in 1997 (Mulvey & Nicholson, 1999). This study involves laboratories in physics and the use of computers. Gender differences have been shown to exist in both of these areas.

One possible reason that computer use could interact with gender is due to the fact that computers arose from the mathematical and science fields, which have traditionally been male-dominated. Having originated in these fields could produce an inclination towards male-dominated thinking and usage patterns (Mangione, 1995).

Many studies have shown that teachers interact differently with their male and female students (e.g. Sadker & Sadker, 1994; and AAUW, 1992). Tobin and Garnett (1987) found that males receive more positive interactions with teachers in science activities. This differential treatment is found among students as well. Many teachers and researchers believe that males tend to dominate mixed-group interactions. Heller and Hollabaugh (1992) found this was true on a written problem-solving task. In labs, Kahle (1990) found that a relatively small group of males dominated interactions with equipment in a science laboratory. There are certainly differences in how males and females interact with other students and equipment in laboratory settings. When dealing with mixed-gender groups, it is important to keep in mind these differences.

Computers are also perceived as gender-biased. Males tend to use the computer more outside of school, and tend to use them for themselves, while females use them as a tool to get things done (Cheek & Agruso, 1995, and Shasaani, 1997). Females are often perceived as computer phobic, although the research is split between those who find females more phobic and those who find no differences (Guttschow, 1999). Busch (1996) and Comber, Colley, Hargreaves, & Dorn (1997) found that females enjoyed the computer less than males and felt less comfortable using them.

In terms of achievement using computers, several people have found that males do better than females on tasks involving the computer (Brasell, 1987; Barbieri & Light, 1992; Kutnick, 1997; and Stuessy & Rowland, 1989). Berge

(1990) compared how girls and boys learn science process skills with the computer and found no gender differences. When working with computers in a science laboratory, it is unfortunate but reasonable to expect to see some gender differences, and so it is important to examine this issue.

Summary:

As is evident from the sections above, few studies have taken into account the larger classroom environment and instructional paradigm when studying the effects of computers in the classroom. It is also rare to see research taking a multilayered look at the many different dimensions of classrooms: achievement, attitudes, and actions of students. There is a great deal of research on different specific effects of using computers in the classroom, but none have looked comprehensively at how a computer affects the whole. This study will take a close look at how VideoTool affects several different parts of the learning experience.

Instructional Paradigms

The ways we can teach are nearly as varied as those who are teaching. Until recently, it was difficult to categorize different styles of teaching. In a 1994 article, Farnham-Diggory proposed that only three core instructional paradigms exist, and all instruction will fall into one of these three categories. Her three paradigms were behavioral, developmental, and apprenticeship. Each instructional paradigm is determined by two factors: the nature of the expert-model distinction, and the mechanism by which a novice becomes an expert.

Behavioral:

In a behavioral paradigm, one distinguishes a novice from an expert by comparing the two on the same scale. A novice performs at a lower level than an expert. The manner in which a novice becomes more expert is one of incrementation: the process is step-by-step, each step bringing the novice towards the expert. An example of a behavioral practice is that of learning to use a keyboard. The novice types few words per minute with many mistakes; the expert types many words per minute with few mistakes. As a novice learns to type, she or he moves slowly up the scale of words per minute, making fewer mistakes. In a school setting, Farnham-Diggory (1992) recounts a remedial reading program in which students learn phonograms and grammar rules and methodically build a personal list of vocabulary words. This step-by-step process takes remedial readers and helps them move towards more expert reading.

Developmental:

A developmental instructional paradigm distinguishes experts from novices by their personal qualitative understanding of concepts and principles. A novice's understanding will differ in many ways from the expert's understanding. The process of transforming a novice into an expert involves perturbation—the novice's understanding is probed and challenged until the novice generates a different, more expert-like understanding. This paradigm is growing popular in science curricula, as teachers draw out students' personal conceptions and then expose the students to various phenomena which lead the students to develop more acceptable understanding. An example of this type of curricula is the Constructing Physics Understanding project (The Learning Team, 2000). Students complete sets of activities with particular purposes: the initial activities draw out students' current ideas and conceptions about a particular phenomenon, such as lighting a bulb with a battery. Then students work through several activities which are carefully designed to help the students develop scientifically acceptable understanding. After the development of the ideas, students work through several more activities which help them flesh out the ideas and verify their usefulness. The developmental paradigm does not rely on quantifiable measures to distinguish the novice from the expert; rather it relies on qualitative models of understanding.

Apprenticeship:

The third instructional paradigm which Farnham-Diggory proposes is apprenticeship. In apprenticeship, novices and experts exist in different worlds or cultures. A novice enters a different world, participates in this new world, and slowly becomes acculturated into this new way of thinking about the world around them. Many traditional crafts have been learned through this process. Typically a novice is apprenticed to a master, and through many years of training, learns the craft and becomes a master himself or herself. In a school environment, many such cultures exist. The physics teacher is a master of physics; the reading teacher is a master of reading. Industrial tech courses often employ an apprenticeship approach. A common academic apprenticeship environment is that of graduate school. The young student apprentices him- or herself to a research group. At first, the student watches what goes on and is assigned small tasks related to the main work. As the student learns about the group, he or she is assigned more tasks and is watched over by older graduate students and the professor. By the end of the student's graduate school career, they have learned the specific tasks taught in the group and can help the new group of young students. By first watching and then trying to do things, the student can learn the myriad skills and knowledge involved in creating and repairing things.

Cognitive apprenticeship (Collins, Brown, & Newman, 1989) is an apprenticeship approach specifically focused on learning complex skills in school environments. It has successfully been used in a variety of disciplines. Collins et. al. describe three different classes in reading comprehension (Palincsar & Brown, 1984), writing (Scardamalia & Bereiter, 1985) and mathematics problem solving (Schoenfeld, 1983 and 1985) which use apprenticeship methods. Others have used cognitive apprenticeship techniques to teach instructional design (Ertmer & Cennamo, 1995), Doppler radar for weather forecasters (Casey, 1996), engineering (Smith, 1988) and computer programming (Chee, 1995).

There are several key points to cognitive apprenticeship. The difference between experts and novices must be explicit. Students must realize that they are starting as novices, and the teacher as an expert can help them become more expert. As with traditional apprenticeships, the student must be a part of the expert's world. This means that learning must be situated in an authentic environment with authentic problems. Decontextualized, unrealistic problems are not a part of either the novice's world or the expert's world. Given an appropriate environment, the expert and novice begin by having the novice student observe the expert teacher as she or he models the target process (e.g., solving a physics problem). The student then tries to duplicate the process under the supervision of the teacher. Successive attempts with guidance from the teacher bring the student closer to a successful trial. As the student continues to attempt the process and begins to understand what is required, the teacher can slowly decrease the amount of help she or he gives the student. This process can be labeled in three steps: modeling, coaching, and fading. Throughout the entire process, it is the alternation between expert and novice performance and the reflection upon the differences between them that leads the student to become an expert.

Apprenticeship in College Physics:

The apprenticeship approach to teaching physics is uncommon. In the past, most physics courses took a behavioral approach to teaching physics through problem solving: an expert can solve all the problems in the back of the textbook chapter (or test questions), and a novice can solve none. By the end of the course, a good student has become more expert-like and can solve many textbook or test problems. In contrast, the recent reform movement takes a different approach. Most new instructional designs in college physics teaching are developmental-based, or use developmental techniques within a behaviorist pedagogy.

The introductory physics course in this study uses the Cooperative Group Problem Solving instructional system, which has a model-coach-fade pedagogy. The goal of the course is to teach physics through problem solving. This means that the students should leave the class solving problems in a more expert-like fashion than when they entered the class. To reach this goal, the teachers must model the problem-solving process, coach the students as they attempt problem-solving, and eventually decrease the level of support to allow the students to solve problems on their own. The modeling of problem solving occurs in lecture. The lecturer talks about the physics principles and also solves appropriate physics problems in front of the students. The students observe this expert behavior. The students then go to their labs and recitations, where they solve appropriate problems in cooperative groups under the guidance of a teaching assistant. The teaching assistants provide coaching to the students as they attempt to replicate more expert-like problem-solving behavior. Students also have access to peer coaching through the use of cooperative groups and group role structures. Students later solve problems on their own with little or no guidance during tests and on homework assignments. Through this process of modeling the process, coaching the students as they try the process, and fading out the amount of support given to the students, the novices become more and more expert-like in their problem-solving behavior.

Since very few college physics courses use an apprenticeship paradigm, little research is available on how adding computers to an apprenticeship course can affect students. Because of this difference in pedagogical style, this study can expand what is known about adding computers to physics classrooms.

Instructional Paradigms for Laboratories

Just as there are different ways to structure a learning environment, there are different ways that labs can be used within a learning environment. Farnham-Diggory (1994) states that the three instructional paradigms are mutually exclusive; however, she allows that different models may be working as "modules" within a larger parent paradigm. In this sense, laboratories may appear to be following any of the three types of instructional paradigms even though the overarching instruction is of one type. In this section, I will describe laboratories which fall into each of the three types of instruction. Then I will describe the laboratories used in this study.

Behavioral:

Behavioral laboratories are focused on getting students to do more, do it faster, or do it better. A common phrase for this type of laboratory is "drill and practice." Students use the laboratory to practice a certain skill or technique in order to gain mastery over it. A common laboratory goal for this type of instruction is to gain technical skills, and a typical laboratory workbook would include careful instructions on how to complete each step of the lab.

Developmental:

A developmental laboratory is one that focuses on perturbation. Students are presented with a phenomenon, and are asked to consider their understanding of the concepts underlying the phenomenon. Students then observe the phenomenon, which is often chosen because it will demonstrate surprising or unexpected results. Students then reflect on the observation and compare the results to their current model of thinking. This process eventually leads the student to change their understanding of the concepts to a more expert-like understanding. The *Tutorials in Introductory Physics* by the Physics Education Group at the University of Washington (McDermott, Shaffer, and the Physics Education Group at the University of Washington, 1998) are good examples of developmental activities. The tutorial worksheets have students predict what will happen in a situation, then observe the situation, and reflect and discuss the concepts which could explain the observations.

Apprenticeship:

An apprenticeship laboratory has students working with an expert and performing at least some parts of the model-coach-fade process. Students practice the target process with some level of support from the expert. The course used in this study uses the laboratory as part of the coaching process. In this cognitive apprenticeship laboratory, students work in groups solving physics problems (the target process). The instructor, usually a graduate teaching assistant, works as a coach, giving helpful hints when necessary and keeping the groups on track without giving too much guidance. The laboratory uses contextually appropriate problems which are directly tied to the lecture. Students see the problem-solving process modeled in lecture, then go to the laboratory and try to replicate the process.

There is a large group of laboratories that does not fall into one of these three paradigms, however. A traditional physics laboratory consists of students verifying physical principles using some sort of equipment. Often the needed derivations and manipulations are given to the students as a sort of recipe, hence the name "cookbook labs." I argue that these types of labs do not belong to any of the three paradigms because they are instructionally goal-free. They do not connect to the larger instructional design of the course, nor do they match the goals of the three paradigms.

Ask the instructor of this type of lab why he or she uses a lab, and their response is often that physics students *need* to work in a laboratory if they are learning physics. "Since professional scientists work in laboratories at some or all stages in their careers, then student scientists must also work in laboratories. So runs the rationale for laboratory work." (Hegarty-Hazel, 1990, p. 3) This is hardly a good instructional reason to use labs. Yet many physics courses use expensive resources and time to show students how to verify that the principle they read in the book does actually work. But students are not learning from these laboratories. Several groups have found that traditional laboratory instruction does not affect students' class achievement (Hofstein & Lunetta, 1982; Stake & Easley, 1978; Tobin & Gallagher, 1987; and Toothacker, 1983). Most of these people agree that laboratories can be useful, but not as presently implemented.

Another issue in examining college physics laboratory instruction is that in many classrooms the laboratory is separate from the course, in instructor, content, goals, or any combination of the three. Many of the laboratory curricula mentioned here could be used in any type of physics course—they are separate pieces to be added wherever needed. Much of the research on laboratories focuses on this modular type of laboratory, disconnected from the paradigm of the related course.

Given the three types of instruction, it is not surprising that different types of laboratories fall into the three paradigms as well (or do not belong at all). In the college physics class used in this study, the laboratories are part of the cognitive apprenticeship paradigm. This type of laboratory is uncommon in physics instruction. Since the laboratory is an integral piece of the course, it is impossible to examine the effects only in the laboratory. A few other colleges use this type of laboratory, but the amount of research done on this type of lab is minimal. This study can make a contribution to the field of research on laboratories by examining the effects of adding a computer data collection and analysis tool (VideoTool) to laboratories using a cognitive apprenticeship approach.

Laboratory Computer Use and Instructional Paradigms

This study focuses on the effects of adding computers to a certain physics laboratory pedagogy. Much research has been done on how adding computers affects specific aspects of laboratories, but little research has focused on the larger environment including aspects of how the pedagogy of the class interacts with the computer to affect achievement, attitudes, and actions of students. Few studies of computer effects include the underlying pedagogy of the class being studied. This section will review the different ways that computers can be used with different instructional styles.

Behavioral:

For a behavioral laboratory using computers, "drill and practice is undoubtedly the most common use of microcomputers in school." (Lazarowitz & Tamir, 1994, p. 103). The computer is an untiring teacher, able to provide countless scenarios, each slightly different, until students learn the desired skill or knowledge. In physics, Griffin and Turner (Griffin, 1990) have created two computer tutorials on motion and acceleration. The tutorial teaches students about various representations of motion: verbal, strobe records, and graphs. While the "software controls the content and order of presentation…the student controls the pace and can repeat a step at any time." The goal is to have the students learn how to understand various representations of motion by repeatedly visiting these representations.

Developmental:

A growing number of computers are used in conjunction with developmental instruction. Most often the computers are used as a tool to provide the situations and phenomena that students encounter. Several physics curricula follow such a pattern: Workshop Physics (Laws, P.W., 1997) and RealTime Physics (Sokoloff, D. R., Laws, P.W., & Thornton, 1994) are two examples. Workshop Physics is a lab-based curriculum for introductory college physics which uses the computer as a data gathering and analysis tool. Students collect data with videos or probes, the data is sent to the computer and is analyzed by the student on the computer. The curriculum is designed to help students develop scientifically appropriate models of various physics concepts through exposure to and reflection upon many phenomena. RealTime Physics has a very similar curricular goal, though its structure differs. RealTime Physics is used with a traditionally structured physics course as the laboratory component of the course. The activities "use a guided discovery approach to allow students to take an active role in their learning and to encourage them to construct physical knowledge for themselves from actual observations" (Thornton & Sokoloff, 1997, p.1105). One difference between these two curricula is that Workshop Physics is a complete curriculum in which every piece of the course is designed to achieve a common goal. With RealTime Physics, the computer can be used in this developmental laboratory while the lecture and other parts of the course may have a different instructional paradigm and different instructional goals. In many courses, the goals for using computers in laboratories are separate from the overarching paradigm and goals of the course.

Apprenticeship:

The cognitive apprenticeship approach to teaching can also be aided by developing technology. In a seminal paper on cognitive apprenticeship, Collins, Brown and Newman asserted that "appropriately designed computer-based modeling, coaching, and fading systems can make a style of learning that was severely limited, cost effective and widely available" (Collins, Brown, &

Newman, 1989). Several people have tried such techniques (e.g., Reif & Scott, 1999).

Less research, however, has focused on using the computer as part of the culture of learning, as an appropriate tool. Chee (1995) used cognitive apprenticeship to teach computer programming of the Smalltalk language and found it to work well. For Chee's classroom the computer program was designed specifically to provide modeling, coaching, fading, articulating, reflection, and exploration.

For this study, the computer was an important tool used to help the students solve physics problems. The computer program VideoTool was designed to match the instructional paradigm used in the course. Students are required to give predictions and examine outcomes and make many decisions in their groups. Very little research has been done on how computers can be used in cognitive apprenticeship environments.

Summary

There is a great deal of research available on the topic of computers in the classroom. However, much of the research is very limited in scope, looking only at achievement, or attitudes, or gender effects. The research is also contextually blank, because most of the studies never describe the larger context of the course being examined. Pedagogical issues and instructional goals appear only rarely in this literature.

This study will expand the body of knowledge in this field in two ways. First, it takes a comprehensive look at the effects of adding a computer data collection and analysis tool to one part of a course, the laboratory. Since the laboratory is an integral part of the course, it is necessary to examine the effects in the whole course. Overall achievement and attitudes in the course will be examined alongside the effects in the laboratory itself.

The second way this research contributes to the field is through its pedagogical underpinnings. This research took place in a specific instructional environment, and this environment cannot be ignored when looking at the results of the study. The cognitive apprenticeship paradigm is rarely used in college physics teaching, and little research has been done in this paradigm. This particular college physics course is also a complete system, with one instructional paradigm supporting every part of the course, and each carefully designed part of the course is necessary to the whole. Much of the current research on using computers has taken place in modular laboratories or classrooms, where the instructional paradigm and goals of the laboratory are disconnected from the goals and paradigm of the rest of the course. This research moves the field in directions which have been previously ignored.

Chapter 3 Methods

Overview

This study used a quasi-experimental design to look at the effect of adding computers as a tool in a physics problem-solving laboratory. The main research questions were to determine whether students achievement, attitudes, and group behavior were different for students using a computer data collection and analysis tool (computer treatment) and students using traditional tools (traditional treatment), and if there were any gender-treatment interactions. To answer these research questions, groups of students were observed in the laboratory setting, and students took two conceptual tests as well as a course evaluation survey. The computer and the traditional treatment groups were compared on each of these as well as on other measures. This chapter describes in greater detail the experimental setting, selection of participants, and instruments used, and the way the data was analyzed.

Quasi-Experimental Setting

This study took place in the physics department at a large midwestern research university. The Physics Education Research and Development Group had made a decision to add computers into the laboratory of the large introductory calculus-based course. This course serves over 800 students a year, and consists primarily of engineering and physics majors.

Structure of the Course:

The structure of the course follows a traditional lecture-lab-recitation format, but the instruction follows a non-traditional pedagogy. The main goal of this course is to have students learn physics through solving problems. To reach this goal, the course uses a Cooperative Group Problem-Solving (CGPS) approach (Heller, Keith, & Anderson, 1992; and Heller & Hollabaugh, 1992). Students in lab and recitation work in small cooperative groups to solve contextually rich physics problems.

The theoretical framework supporting the course is one of cognitive apprenticeship (Collins, Brown, & Newman, 1989). Cognitive apprenticeship courses include three levels of instruction: modeling, coaching, and fading. In this course, the lecturer models good problem-solving practices in the lecture section; the teaching assistants coach students in problem solving in the laboratory and recitation sections, and support fades as students complete homework and tests. The laboratory is an essential part of this framework. Students sign up for a paired laboratory and recitation, with the same 18 students in both, and the same instructor for both.

Structure of the Laboratory:

In the Cooperative Group Problem-Solving pedagogy, laboratories are a chance for students to practice solving physics problems under the guidance of a coach (the teaching assistant), and with help from their peers. Each "lab" consists of a series of two to six physics problems that are solved over a two to three week period. Students work in cooperative groups to solve several related problems during the two or three week lab. Table 3.1 shows a list of the typical laboratories and problems for the first term of calculus-based physics.

Most of the Teaching Assistants for this course are physics graduate students, though other undergraduate and graduate students with appropriate backgrounds sometimes teach as well. All TAs for this course receive extensive education in how to teach in this department. A required four-credit course covers educational research, the teaching structure at the University of Minnesota, teaching techniques that TAs can employ, and general teaching advice. Teaching Assistants also receive ongoing support from mentor TAs, who visit recitations and laboratories and provide feedback and advice to new TAs. The teaching assistants for both the computer treatment and the traditional treatment took the same orientation course, and they had the same mentor TAs. The 7 TAs teaching the computer treatment sections received, in addition, a few hours of instruction in how to use the computers and the new software before the quarter began. They also had help available when teaching the laboratories.

Table 3.1

Laboratories and Problems for First Quarter Calculus-Based Physics

Introduction

Laboratory I: Description of Motion in One Dimension

- * Problem #1: Constant Velocity Motion
- * Problem #2: Motion Down an Incline
- * Problem #3: Motion Up and Down an Incline
- * Problem #4: Motion Down an Incline With an Initial Velocity
- * Problem #5: Mass and Motion Down an Incline
- * Problem #6: Motion on a Level Air Track With an Elastic Cord
- Check Your Understanding
- Laboratory I Cover Sheet

Laboratory II: Description of Motion in Two Dimensions

- * Problem #1: Mass and the Acceleration of a Freely-falling Object
- * Problem #2: Projectile Motion and Velocity
- * Problem #3: Projectile Motion and Mass
- * Problem #4: Acceleration and Circular Motion
- * Problem #5: Radius and Circular Motion
- * Problem #6: A Vector Approach to Circular Motion
- Check Your Understanding
- Laboratory II Cover Sheet

Laboratory III: Forces

- * Problem #1: The Slingshot
- Problem #2: Forces in Equilibrium
- * Problem #3: Normal Force and the Kinetic Frictional Force (Part A)
- * Problem #4: Normal Force and the Kinetic Frictional Force (Part B)
- Table of Coefficients of Friction
- Check Your Understanding
- Laboratory III Cover Sheet

Laboratory IV: Energy Conservation

- * Problem #1: Kinetic Energy and Work on the Air Track
- * Problem #2: Energy and Collisions When the Objects Stick Together
- * Problem #3: Energy and Collisions When the Objects Bounce Apart
- * Problem #4: Energy and Friction
- Check Your Understanding
- Laboratory IV Cover Sheet

Laboratory V: Momentum and Energy Conservation

- * Problem #1: Perfectly Inelastic Collisions on an Air Track
- * Problem #2: Elastic Collisions
- Check Your Understanding
- Laboratory V Cover Sheet

* Experimental treatment used VideoTool

The two-hour weekly laboratory section of the course is tied directly to the rest of the course. The content addressed by the laboratory is the same content students encounter in the lecture and the recitation for that week. Students must prepare for each two to three week lab before it begins by taking a short computer quiz which requires that the students have read the appropriate parts of the textbook. The laboratory instructor checks that every student has taken this quiz before lab begins. If not, that student is not allowed in lab that week. Before every weekly lab session, the students must have read the assigned laboratory problems and made predictions for those problems. These predictions are checked by the lab instructor within the first few minutes of class.

After the instructor has checked the students' predictions, he or she leads a whole-class discussion on those predictions. This discussion draws out issues surrounding the problem and possible physics misconceptions. The students are not given the correct answer at this time, as the goal is to have them solve this problem in their groups. After the discussion, the groups work on solving the problem.

The laboratory manual does not give them explicit instructions as to how to solve the problem, but leads them through general problem-solving steps. An example lab problem is included in Appendix E. There are three main parts of the lab: exploration, measurement, and analysis. The groups work on the problem by exploring the available equipment, developing a measurement plan, and collecting and analyzing data. Once they have reached a conclusion for this problem, they move on to the next problem.

Before the end of lab, the instructor stops the groups and leads another discussion of results and conclusions. By comparing the results of all of the groups to their predictions, the class decides upon the correct solution to the problem. Students leave the lab with the problem solved. There is no data taken out of the lab, no analysis worked on at home. All work is done in the laboratory except for a short lab report on one of the problems, assigned every two to three weeks at the end of the lab. All work in the laboratory is also done in a group. The lab problem reports are the only individual piece, with each member of a group assigned a different problem to write up.

Traditionally, computers have not been a part of this problem-solving laboratory. For the first quarter mechanics course, students have used spark timers, air tracks and similar equipment to take their data. A typical solution to a problem would involve students collecting data by having a cart slide down an air track. As the cart moves, it makes a spark dot at regular intervals on a long narrow piece of spark tape. Students can then examine the spark tape, and knowing the time interval between spark dots, they can calculate velocities, accelerations, and forces. Data analysis was done by hand or with calculators in the lab. All data and analysis was worked on in the student's laboratory journal.

<u>Computer-Based Data Collection and Analysis Tools:</u>

When planning to implement a computer tool into this course, several design principles were followed. The most important was that the computer tool match the pedagogy of the lab. The computer tool had to be easy to use, so that students did not need to spend a lot of time learning how to use it. Since humans are very visually oriented, the computer tool needed to take advantage of how we learn visually. The computer had to be available as a tool for students solving a problem, but it could not be more than that; it must not solve the problem for the students. Scardamalia, Bereiter, McLean, Swallow and Woodruff (1989) proposed the following when using technology:

> In most software design it is presumed desirable to make the software as intelligent as possible and demand as little intelligence as possible from the user. Educational applications, on the other hand, should be aimed at developing the intelligence of the user. Educationally irrelevant burdens should be minimized, but not in ways that deprive students of occasions to develop the planning, monitoring, goal-setting, problem-solving and other higher-order abilities that are important objectives of education. (p. 53).

Because of these principles, none of the commercially available software packages would work. Most available software does not include a place for predicting what will happen, an integral part of this course's laboratory design. Also, much of the available computer software uses probes and sensors. The Physics Education Research and Development (PERD) Group wanted to take advantage of human visual capabilities, so for the first quarter of mechanics, this meant using video and video analysis. Several video analysis programs are available, such as VideoPoint (PASCO Scientific), but again, they do not include prediction options. Because of these requirements for software, the PERD Group designed its own software.

To create the software, the group used LabVIEW™ from National Instruments as the underlying program. LabVIEW™ is very common in industry and research labs, and many science and engineering students use this program later in their schooling or career. It works with both Macintosh and Windows operating systems. LabVIEW™ also has an intuitive interface, which means less time is spent by students in learning how to use the program. The actual programming of this software was done by Dr. Theodore Hodapp, a professor of physics at Hamline University. Working with Dr. Hodapp, the group came up with design ideas and started creating the software, called VideoTool, for the Macintosh computer. It went through many different versions, and was pilot-tested in the summer classes before being used in this study.

VideoTool is used with a small security-type camera as input. Students, in groups of three, take a movie (video) of the desired motion using Apple Video Player, a video capture program that is included with modern Macintosh computers. They then open up VideoTool. In VideoTool students are asked to input their predictions for the X-motion and Y-motion they just videotaped. These predictions should have come from measurements and estimations the students made as they took the data movie. Their predictions appear on graphs of X versus time and Y versus time, at the bottom of the screen. Then they open up their movie within VideoTool. Using a point of reference that has been placed in the movie background as a reference (such as a meterstick), they assign a reference length, so that the computer can make calculations consistent with the actual size of the objects. Then students follow the motion of the desired object with the mouse, taking one data point for each frame of the movie. This data appears dot by dot on the appropriate graph below the video, so students can see the data graphed as they watch the motion of the object. The same graph displays the group's prediction, so that the students can also compare their prediction to the data.

Once the data is collected, students fit the X-data with a function. The program does not do any of the fitting. Students need to choose all functions and parameters to best fit their data. The program has many available base equations from which to choose, from a linear function to exponentials. Once students have chosen the function, they then choose the values for the parameters in the function. Students fit the Y-data in a similar manner.

Students then predict the velocity graphs in both the X and Y directions, using their fitted functions of the X and Y data to make their prediction. The computer analyzes the X and Y data and produces Vx versus time and Vy versus time data on appropriate graphs. The Vx and Vy graphs include the group's prediction. Then students fit the new velocity data as best as they can, again comparing their prediction to their fitted data. Finally, the third round begins, with students predicting the acceleration in the X and Y motion, using their velocity fits as a guide. The computer calculates the acceleration data, displays it with their prediction, and students fit the acceleration data.

Once students have completed this analysis, they can print out a copy of the results. This printout includes all six graphs: X, Y, Vx, Vy, Ax, and Ay. The graphs show the predicted function and the fitted result, and above the graphs are listed the predicted and fitted functions including all parameter values. This printout becomes part of the group's lab journal, and should be included in the students' lab reports. An example of a printout is included in Appendix F.

Treatment:

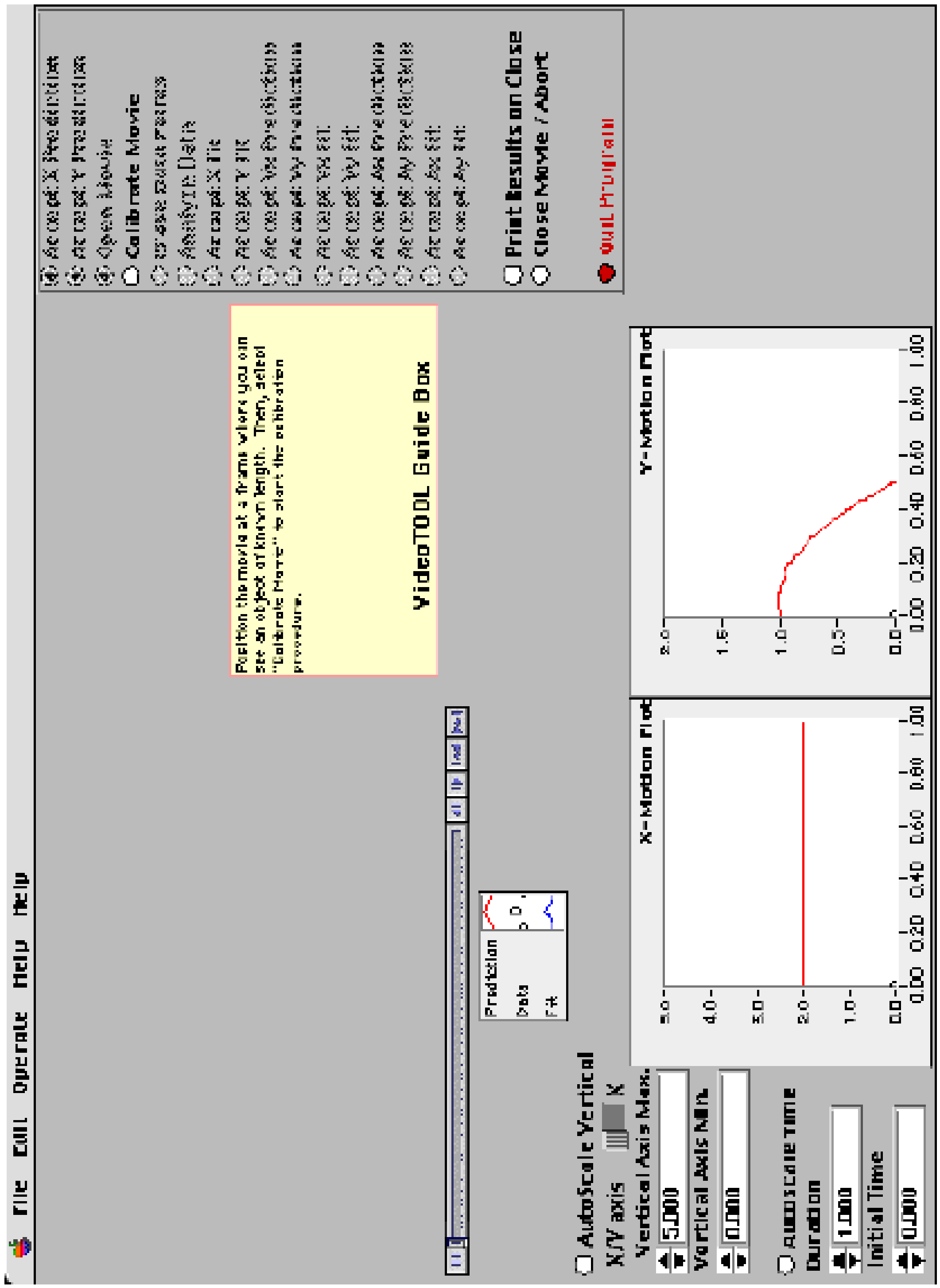
Introducing a computer tool into this laboratory changes very little. Instead of collecting data by hand, students manipulate a computer program to collect and analyze video data. The data analysis is done ***on*** the computer, but not ***by*** the computer. Students must still make every data collection and analysis decision, from units to line fitting. In essence, the only differences between the computer treatment labs and the traditional treatment labs are the tools used to collect and analyze data. Students in both labs must decide what data to collect and how to collect it. They must decide what is the proper analysis of this data and how to conduct it. They draw their own conclusions from their own analysis.

Table 3.1, shown earlier, lists the number of laboratory problems in this course that required the use of VideoTool, marked with an asterisk (*****). As shown, all but one of the problems used VideoTool.

Selection of Participants

The introductory course used in this study was taught by five different lecturers and 27 different Teaching Assistants. Not all of the sections of this course were used in the study. Of the five professors, one professor has

Figure 3.1 Screenshot of VideoTool



a history of teaching very differently and receiving significantly different results on some of the measures used in this study.Another lecturer's section, taught later in the day, includes a different population of students, with more older and non-traditional students. For these reasons, only three of the five lecture sections were included in the study.

Teaching assistants are assigned to lab / recitation sections by the department, based on the TAs' class schedules and available teaching times. Those in charge of assignments were asked that half-time TAs be assigned consistently to either two computer treatment labs or two traditional treatment labs. This was the only constraint this study imposed on TA assignments. The standard assignment system produced a random mix of people: some first-year graduate students, some older graduate students, some good TAs, and some poor TAs.

Approximately half of the 27 lab sections were assigned to each treatment. Ideally, the 27 lab sections would be randomly and evenly split among the three lecture sections and the two treatments. This did not happen because there were two constraints on assigning laboratory sections to treatments. The first constraint was a limitation on the physical resources available. Four lab rooms were available for the course; only one of which was set up with computers. Another constraint was that each half-time TA needed to teach two labs in the same treatment. This further limited the possible assignments of lab sections to treatments. Based on the times of the lab and recitation, which were previously decided upon by the department, and these two constraints, sections were assigned to be either a computer or traditional treatment.

Students who registered for this course signed up for a recitation/lab section which fit their schedule. They did not know in advance whether or not their section would use computers in the laboratory. Although students were allowed to switch sections during the first week of class, unless they knew someone in another lab, they would not know if the other lab would use computers.

Table 3.2 shows the number of students in each treatment by instructor and laboratory section.

Table 3.2

Distribution of Students by Lecture and Lab Section

	Computer Treatment			Traditional Treatment		
	TA	Section	# of students	TA	Section	# of students
Lecturer A	1	1	12	4	4	16
		7	12		6	13
	2	2	15	5	5	15
		8	14			
	3	3	15			
		9	15			
Lecturer B	1	11	16	3	10	12
		15	16		17	15
	2	14	16	4	12	12
		16	16		18	13
				5	13	11
Lecturer C	1	32	13	3	33	17
		39	13		40	18
	2	36	12	4	34	14
		37	15		38	11
				5	35	14
Totals	7	14	200	6	13	181

Methods and Instruments

The research questions in this study will be examined in several parts: achievement, attitude, and group behaviors. In order to understand how adding a computer tool to the laboratory affects each of these components, it is necessary to examine each of these separately. Thus several different instruments are necessary.

Quasi-equivalence of groups:

Because this study used a non-equivalent control group design in which students could not be randomly assigned to treatments, it was important to determine how similar the two groups were on various measures that could affect achievement, attitude, and group behaviors. Fifteen background variables could affect these three dependent variables:

1. Age
2. Workload (number of hours worked per week)
3. Course load (number of credits taken)
4. Grade Point Average
5. Expected amount of study time
6. Physics background
7. Repeating this course
8. High school math background
9. College math background
10. Calculus prerequisite
11. Computer literacy
12. Feeling of preparation for this course
13. Expected grade in this course
14. Force Concept Inventory pretest
15. Test of Understanding Graphs-Kinematics pretest

A questionnaire was designed to measure the first thirteen background variables. These questions can be found in Appendix A. The two conceptual tests are described in the next section. The background questionnaire and the two conceptual tests were administered to all students during the first week of lab.

Achievement:

The first research question was:

1. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change students' achievement?
   a. Do students in problem-solving laboratories with VideoTool (experimental treatment) gain equally well as students in problem-solving laboratories with traditional tools (control treatment) on a test of understanding kinematics?
   b. Do students in the two treatments gain equally on a test of understanding force?
   c. Do students in the two treatments do equally well on overall course grades?

Three separate measures of achievement were used. One measure was a locally constructed measure of achievement (course grades). The second and third were nationally normed conceptual tests. By examining results on these two types of measures, one can gain a sense of how using the computer tool affected both local achievement on a measure designed specifically for this course as well as more global achievements.

The first achievement measure was course grades. Course grades demonstrate both how well the students did in the entire course, and also in the laboratory portion of the course. The laboratory portion of the grade was typically 15%, while problem solving was from 65% to 85%. Using course grades is one measure of student performance, if not complete student understanding. Grades are also a concern when changing instruction in a course. If adding VideoTool to the laboratory had an effect on students' grades, this would be a concern for the current instructors, future instructors, and administrators, as well as for the designers of the lab.

The second achievement measure was the Force Concept Inventory (Hestenes, Wells, and Swackhamer, 1992). The Force Concept Inventory, or FCI, is a widely used physics test of students' conceptual understanding of forces. The 30-question multiple-choice test has been demonstrated to be valid and reliable. The entire test is included in Appendix B. Table 3.3 gives two example questions from the Force Concept Inventory. The FCI was chosen for two reasons. First, the FCI has been given in hundreds of schools across the country, including at the University of Minnesota, as an overall measure of effectiveness of instruction (Hake, 1998). Second, the FCI has also been used in the introductory course at the University of Minnesota for several years as a measure of student achievement.

Table 3.3

Two Example Questions from the Force Concept Inventory

4. A large truck collides head-on with a small compact car. During the collision:

(A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
(B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
(C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
(D) the truck exerts a force on the car but the car does not exert a force on the truck.
(E) the truck exerts the same amount of force on the car as the car exerts on the truck.

25. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed "v_0".
The constant horizontal force applied by the woman:

(A) has the same magnitude as the weight of the box.
(B) is greater than the weight of the box.
(C) has the same magnitude as the total force which resists the motion of the box.
(D) is greater than the total force which resists the motion of the box.
(E) is greater than either the weight of the box or the total force which resists its motion.

The third measure of achievement was a relatively new conceptual test called the Test of Understanding Graphs-Kinematics, or TUG-K (Beichner, 1994). The test consists of 21 multiple-choice questions which probe students' understanding of the relationship between kinematics variables (position, velocity, and acceleration), and students' ability to interpret and create kinematics graphs. Appendix C includes the entire test. Two example questions from the test are shown in Table 3.3. This test focuses solely on the graphical representations of kinematics variables such as position, velocity, and acceleration.

This test does not have the history that the FCI has, but has been field-tested and proven to be valid and reliable (Beichner, 1994). Because of the nature of the laboratories in this course, and the nature of the computer tool used, it is reasonable to assume that adding the computers to the laboratory might affect students' ability to create and interpret graphs. The TUG-K is the best tool available to study students' kinematics graphing understanding with large numbers of students.

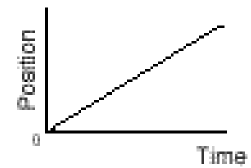
The Force Concept Inventory and the Test of Understanding Graphs-Kinematics were both given as a pretest in the first week of the course. These were both given on a voluntary basis, and were not graded. The TUG-K was given as a posttest in the last week of the lab, during the tenth week of instruction. Again, it was given voluntarily and was not graded. The FCI was given as a posttest on the final exam, after ten weeks of instruction, and performance was considered part of the final exam score. The course grades were collected at the end of the quarter.

Table 3.4

Two Example Questions from the Test of Understanding Graphs-Kinematics

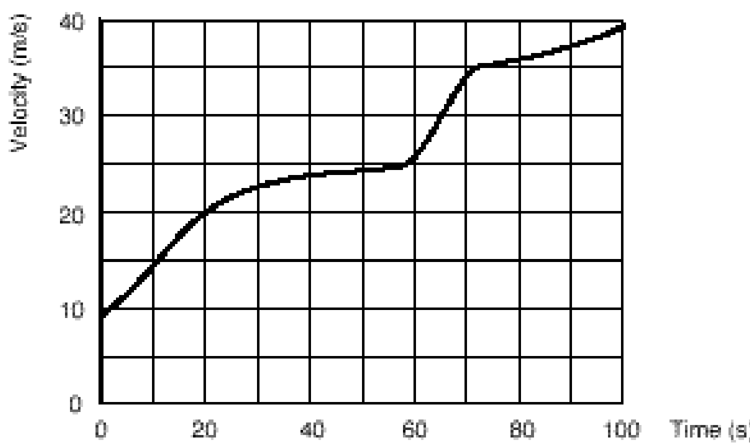
3. To the right is a graph of an object's motion. Which sentence is the best interpretation?

(A) The object is moving with a constant, non-zero acceleration.
(B) The object does not move.
(C) The object is moving with a uniformly increasing velocity.
(D) The object is moving at a constant velocity.
(E) The object is moving with a uniformly increasing acceleration. 0



7. The motion of an object traveling in a straight line is represented by the following graph. At time = 65 s, the magnitude of the instantaneous acceleration of the object was most nearly:

(A) 1 m/s^2
(B) 2 m/s^2
(C) +9.8 m/s^2
(D) +30 m/s^2
(E) +34 m/s^2



Attitude:

The second research question was:

2. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change students' attitudes?

a. Do students in problem-solving laboratories with VideoTool (experimental treatment) have the same overall attitude towards the course as students in problem-solving laboratories with traditional tools (control treatment)?
b. Do students in the two treatments have the same attitude towards using the specific computer or non-computer tools used in the laboratory?

As part of the ongoing evaluation and development of the introductory physics course, a post-course evaluation is given to students at least once a year. The evaluation also serves as specific feedback for the course instructors. To measure attitudes for this study, fifteen questions were developed and included on the course evaluation survey. The entire survey is included in Appendix D. This survey was given to all students during the lab sessions in the last week of the course. The survey was voluntary, but not anonymous. Students were asked to include their name and section number on the survey in order to match students to treatments.

Attitude Towards Course:

Nine questions were developed to elicit students' attitudes towards the three components of the course: the lecture, the discussion session, and the laboratory. The questions are shown in Table 3.5. The three questions for each course component were designed to measure attitude about the overall usefulness of each component. Kronbach's alpha for the nine questions was 0.79.

Table 3.5

Questions about Students' Attitudes Towards the Course

Lab Questions
Directions: Please rate the extent you agree or disagree with each statement about the lecture by marking the appropriate letter on your answer sheet. A = Strongly Disagree B = Disagree C = Neutral D = Agree E = Strongly Agree 1. The lectures were a waste of time. 2. The lectures helped to clarify ideas from the text. 3. The main points of the lecture were clearly stated and emphasized.
Discussion Section Questions
Directions: Please rate the extent you agree or disagree with each statement about the discussion sections by marking the appropriate letter on your answer sheet. A = Strongly Disagree B = Disagree C = Neutral D = Agree E = Strongly Agree 1. The discussion sections were a waste of time. 2. Solving problems with my group helped me to understand the course material. 3. The discussion problems provided useful guidance for solving problems on the individual exams.
Laboratory Questions
Directions: Please rate the extent you agree or disagree with each statement about the lab sections by marking the appropriate letter on your answer sheet. A = Strongly Disagree B = Disagree C = Neutral D = Agree E = Strongly Agree 1. The laboratory sessions were a waste of time. 2. The laboratory problems helped me to understand the concepts covered in class. 3. The laboratory problems provided useful guidance for solving problems on the individual exams.

Attitude Towards Laboratory Tools:

Six questions were developed to probe students' attitude about the overall usefulness of the data collection and analysis tools. These questions are found in Table 3.6. Kronbach's alpha for the six questions was 0.82. Two matched versions of the survey were created and administered to the appropriate treatment groups.

Table 3.6

Questions about Students' Attitudes Towards the Laboratory Tools

Questions about the Particular Tools
Directions: Please rate the extent you agree or disagree with each statement about the lab sections by marking the appropriate letter on your answer sheet. A = Strongly Disagree B = Disagree C = Neutral D = Agree E = Strongly Agree
1. Although it took time to learn VideoTool, it was time well spent. 2. VideoTool taught me the importance of selecting an appropriate origin and / or axis and meaningful units in solving problems. 3. Using VideoTool helped me understand the equations I used in class. 4. Using VideoTool helped my understanding of derivatives. 5. I found the printed graphs and equations useful in writing my lab reports. 6. I am looking forward to using VideoTool in my next physics course.

Group Behaviors:

The third research question was:

3. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change how groups solve the laboratory problem?

    a. Do groups in problem-solving laboratories with VideoTool (experimental treatment) spend the same amount of time in each part of the laboratory as groups in problem-solving laboratories with traditional tools (control treatment)?

    b. Do groups in the two treatments talk about the same things while solving the laboratory problems?

    c. Do students in the two treatments perceive their group functioning differently?

Two methods were used to answer this question. The first is that of observing the groups as they solve the lab problem. The second is a set of questions about group behaviors given to every student at the end of the course. With these two types of data, it is possible to get a strong sense of whether or not there were any differences in the ways students in the two groups solved the lab problems.

Observation Data:

When attempting to study the behavior of students, a common method is to observe the students in the desired setting. This study used structured time observations by non-participants as the method of looking at the behavior of student groups in the laboratories. Observation studies have certain advantages in certain types of research, particularly when studying non-verbal behavior (Cohen and Manion, 1994). An observer can note particular behaviors as they happen and comment on them appropriately. Since the participants are not being asked to do anything differently, some of the bias can be removed from the research. One can see what is happening in the natural setting. Observations do, however, have disadvantages. Since they rely on human observers, certain biases may enter in from the observer's perspective. One method to reduce this type of error is to have the observers work within a particular structure, such as worksheets or check-off forms (see for example Flanders, 1970). This method was adopted for this study.

Observations can come from a person within the studied group—a participant—or they can come from an outsider (Bailey, 1978). There are certain advantages to both methods. Non-participants can examine behavior as it happens without interference. But a non-participant observer may also be affecting the behavior of the subjects merely by his or her presence, depending upon how aware the subjects are that they are being observed. Participants can talk with their subjects, get a closer look at what is happening. But participant observers may also unknowingly influence the behavior of the subjects by their actions. Each research situation calls for a different method to be used. For this study, non-participant observers were chosen.

Students in the laboratory work in groups of three, interacting amongst themselves and with the TA, and perhaps with other groups as they solve the laboratory problem. With such a large physics course, there were a large number of laboratory sections available to study. During the day, two or three labs were often running concurrently. The researcher needed to be free to move around different labs, fix problems and answer questions from the TAs. A scheme of employing outsiders who would use a very structured coding sheet also introduces less bias. For these reasons, it was decided that the researcher would not do the observing.

Observers were hired by posting a job notice through the University's job service. The job requirements were: (a) the applicants had taken all three quarters of this physics course before, (b) they had good English language skills, and (c) they had a flexible schedule. Six observers were hired for the job, starting in the second week of the quarter. The observers were undergraduates or recently graduated post-baccalaureate students. One was in an engineering program, one was a physics major, and four were in the post-baccalaureate program in science education.

Once the observers were hired, they were trained in the process of observation. First, they were given the coding sheet, the lab manual, a description of the observation process, and a description of codes to study. Then they were "talked through" the process, and each observer visited a week of lab and coded each session. Finally, they discussed their trial week with the researcher to clarify any remaining concerns. Once they were comfortable with the job, they started taking data using the coding sheets.

Observation Instrument:

The coding sheet was drafted before the quarter began. To determine what the coding sheet would look like, the laboratory problem structure (see Appendix E for an example of what a lab problem looks like) was analyzed to determine what a typical student group would talk about: what decisions needed to be made in the various parts of the laboratory, and what were possible interactions among the group. The final coding sheet and the interaction code descriptions are given in Tables 3.7 and 3.8.

The typical observation job proceeded as follows: the observer arrived at class and entered with the students. The observer chose a group to watch based primarily on convenience of seating. The observer listened quietly as the TA checked predictions and ran the opening discussion. Once the groups started working on the lab problem, the observer started recording. Sitting near the group, the observer listed which lab section they were attending, the date and the time. They checked off whether or not the TA explicitly assigned roles to the groups, and whether or not the group followed any assigned roles. This was included since roles are a part of the instructional method suggested in TA Orientation, and using the roles could be expected to change a group's functioning. A brief description of each of the students in the group was entered as a mnemonic for the observer; then they collected data. Every minute, the observer recorded the time, looked up at the group, determined what part of the lab they were in (exploration, measurement, analysis, and conclusion), marked who was speaking, to whom they were speaking, and then the observer coded the type of interaction. The interaction codes and the codes' full names were listed on the bottom of the observation sheet as an aid to the observer. This proceeded for as long as the students are working on the lab problem. No contact was made with the group unless unusual circumstances occurred (e.g., long silences in which it was unclear what is going on). The observers were told to keep themselves as quiet as possible, and to give as little indication as they could that they were taking data on a group. Once the class drew together again for the final discussion, the observers stopped taking data. They sat quietly until class was dismissed.

Table 3.7

Observation Coding Sheet

					Descriptors
Observer					M M/F
Section					S M/F
Date/Time					R M/F
Assigned Roles? Y/N Followed Roles? Y/N					E M/F
Time	Lab	Who's Talking	To Whom	Interaction (+/-)	Comments
		M S R E TA	M S R E TA C		
		M S R E TA	M S R E TA C		
		M S R E TA	M S R E TA C		
		M S R E TA	M S R E TA C		
		M S R E TA	M S R E TA C		
		M S R E TA	M S R E TA C		

Tp: talking physics	Me: managing equipment	S: social / off-task
Td: taking data (C)	Mg: managing group	C: TA computer
Te: exploring (C)	Mt: managing task (C)	N: TA normal (non-computer)
Ta: analyzing data (C)		

The first four weeks of the quarter were used to pilot-test the observation instrument. The researcher held weekly meetings with all of the observers to discuss how the task was progressing, any unusual circumstances, and codings they were unsure about. From these meetings, it was clear that some changes to the coding sheet were necessary. Interactions were occurring which did not have a proper code, so codes were suggested and agreed upon. These changes were made to the coding sheet, and in the meetings it was discussed until everyone was certain what the new changes meant. This pilot-testing continued until the fifth week of the quarter, when everyone had been taking data for at least one

Table 3.8

Interaction Codes and Examples

T_p: Talking physics: "I think that's acceleration, not velocity." "What about friction in our case?"

T_d (TdC): Taking data: "Take a picture now." "Push the button." "Let the cart go."

T_e (TeC): Exploring. "How does this look?" "How does this work?" Exploring is a general term for fiddling around with the equipment before actually measuring and taking data.

T_a (TaC): Analyzing data: "No, it's a-b, not b-a." "I think this equation is the right one." All data analysis in the computer labs should be on the computer - that's what the program is designed to do. So most analysis codes in the computer labs will be TaC.

S: Social/off-task: "How did you do on the test?" "Did you see the game?"

M_e (MeC): Management of equipment: "Move that over there." "Did that work?"

M_g: Management of group/people skills: "What do you think?" "Who's writing this down?" This code is only for interactions that focus on the group itself (how the group is functioning as a group) and the people within the group. Not all groups will have this level of self-awareness. Group roles enhance this aspect of group work. Interactions that focus on where the group is in the lab belong in the next category, task management.

M_t (MtC): Management of task: "We only have ten minutes left." "We need to do this."

C: TA Computer question: "Our program doesn't work." "The computer crashed." This is only if the interaction specifically involves the computer. Follow this code with another code describing more fully the interaction (Ta or Td for example).

N: TA Normal: any non-computer-related interaction with the TA: "Our equipment is broken." "What are we supposed to be doing?" Again, follow this code with another code describing more fully the interaction (Ta or Td for example).

Certain codes can be computer-related. This distinction is made between codes that can be made on computer such as exploring with the equipment, and exploring on the computer, such as playing with the video capture program.

Table 3.9

Questions about Group Interactions

Directions: Please indicate ***how often*** *the following events occurred during laboratory sessions by marking the appropriate letter on your answer sheet.*
A= Hardly ever B= Not very often C= Sometimes D= Quite often E= Almost always

1. Our group discussed equipment difficulties.
2. Our group discussed misunderstandings about the physics.
3. One person in our group did most of the data analysis.
4. I felt I was contributing to our group's solution to the lab problem.
5. Our group worked efficiently.
6. I felt the other members of my group were contributing to the solution of the lab problem.
7. Our group did most tasks together.
8. Our group divided most of the tasks.
9. Our group communicated well with each other, so each member understood what the heck was going on.

week already, and all changes to the coding sheet had been made. The data collection began in the fifth week of the quarter. Because the students change groups every two or three weeks, an observer could not watch the same group for more than three weeks. Thus a sampling of groups was obtained.

Group functioning questions:

Two methods were used to answer the research question about group behavior. The first was to observe the students. The second method was to ask each student to respond to nine questions about how their groups typically behaved. The questions were added to the course evaluation survey (see Appendix D) given to students during the last week of the course. These questions were developed by analyzing good group functioning (Smith, Johnson,

& Johnson, 1995) as it applies to physics problem-solving laboratories. Table 3.9 lists the nine questions.

Gender:

The fourth research question was:

4. Are there any gender-treatment interactions?

   a. Is there a gender-treatment interaction for the three measures of achievement?

   b. Is there a gender-treatment interaction for students' attitudes towards the overall course and towards the particular laboratory tools?

   c. Is there a gender-treatment interaction for how students perceive their group functioning?

To answer these questions, gender data will be collected on the following measures: conceptual tests, grades, and surveys.

Table 3.10

Overall Timeline of the Study

Before the quarter began	The observation worksheet was constructed in draft form. Lab sections were assigned to use computers or traditional equipment. TAs were given their teaching assignments, and those teaching a computerized lab were given training in how to use the computer. All TAs attended the TA Orientation.
Week One of the quarter	A job notice was posted asking for people willing to be observers in the lab. Students in all sections of the course took the Force Concept Inventory and the Test for Understanding Graphs-Kinematics. Students also completed the demographic survey. Some students switched which section they were in.
Week Two	Observers were hired, trained, and started collecting data and pilot-testing the coding sheet.
Weeks Three through Nine	The coding sheet was pilot-tested, and observation data was collected.
Week Ten	Students took the Test of Understanding Graphs-Kinematics as a post-test. Students also completed the course evaluation.
Finals Week	Students took the Force Concept Inventory as part of the final exam for the course.

Summary of Methods:

This study used several different methods to answer the research questions. A demographic questionnaire was given at the beginning of class to help determine the similarity of the two groups. Grades and conceptual tests were used to measure achievement. Responses to questionnaires measured students' attitudes. Structured time observations were made to determine how groups solved the lab problem, and questions were given to students to measure perceived group functioning. By analyzing the data from these different measures, the effects of replacing the traditional data collection and analysis tools with VideoTool can be determined. The overall timeline of the study is shown in Table 3.10.

Data Analysis

To answer the four research questions, several different instruments were used. Each of these instruments requires different analysis. The ways the data were analyzed is described below.

Quasi-equivalence of treatment groups:

To determine if the two groups were quasi-equivalent, first, each of the twelve questions on the background survey were analyzed. A student could respond to each question by answering A, B, C, D, or E. The number of students in each group giving each of the five responses was summed, giving a 2x5 table like the one below in Table 3.11. A χ^2 (chi-squared) test was run on each of the background variables, since the χ^2 is the most appropriate test for categorical data such as this. The χ^2 test requires that no fewer than 80% of the cells in the expected table are less than 5, and that every expected value is greater than 1 (Howell, 1997). In cases where this requirement could not be met (due to low numbers of students choosing certain answers), two or more of the responses were combined so that the requirement was met. Finally, the two conceptual pretests were analyzed using t-tests, since the t-test is most appropriate for distributions of interval data.

Because there are so many questions being analyzed, the probability of encountering at least one false significant difference is increased. To control for this problem when doing multiple statistical tests, a procedure known as

Bonferroni's inequality is applied to each test (Howell, 1997). Bonferroni's inequality states that the probability of occurrence of one or more events must not exceed the sum of the individual probabilities. Thus, if we run ten tests and want to keep an overall α of 0.05, then the significance of each of the ten tests must be equal to or less than 0.005. The typical procedure is to set the level of significance for each test at $\alpha' = \alpha / \#$ of comparisons. For the fifteen questions analyzed here, the level of significance was reduced from 0.05 to 0.003. This method of reducing the level of significance is to control for Type I error: the chance of accepting a result as significant when it is significant only by chance. Results of the equivalence tests are below.

Table 3.11

Age Distribution of Students by Treatment

Age	Computer treatment (N=198)	Traditional treatment (N=179)
17 or younger	3	5
18-19	144	125
20-21	28	33
22-23	11	4
24 or older	12	12

<u>Age</u>:

Computers are a relatively new technology, and younger students have more experience working with computers. Therefore, the age distribution of the two treatment groups was an important factor of equivalence. If one group were older, they might be less comfortable with computers, which could affect the results of the study. Table 3.12 shows the age distribution of the two groups, by showing how many students chose each of the possible responses. A χ^2 test was used to determine any significant differences among the groups. In order to meet the requirements of the χ^2 test, the first two categories were combined to be "19 and younger." The results of the χ^2 test indicated that the two groups are not significantly different in ages (χ^2 (3) =3.77, p=0.29).

Table 3.12

Distribution of Course Credits by Treatment

Number of credits	Computer treatment (N=198)	Traditional treatment (N=179)
0-4	0	1
5-8	2	1
9-12	28	25
13-16	106	90
More than 16	62	62

Academic and workload information:

Various academic factors could also affect the results of this study. The amount of time spent working per week and the number of credits taken for the term could affect both achievement and attitude. A student who has three or four other classes, or who is working many hours a week, has less time to devote to their physics class. This could lead to lowered achievements, as well as less positive attitudes.

Table 3.12 shows the distribution of total course credits for students in each treatment during the term of this study. In order to perform a χ^2 test, the first three categories were combined into one category of 0-12 credits. The χ^2 test (χ^2 (2) =0.51, p=0.78) showed no significant differences between the two groups. Neither group was taking more credits than the other was.

Table 3.13
Distribution of Number of Hours Worked per Week by Treatment

Number of hours worked	Computer treatment (N=198)	Traditional treatment (N=179)
None	94	84
1-10 hours per week	37	33
11-20 hours per week	50	48
21-30 hours per week	14	10
More than 31 hours per week	3	4

The number of students responding to a question about their work hours is shown in Table 3.13. The fourth and fifth categories were combined into one category of "More than 21 hours per week." The results of this question were not significantly different (χ^2 (3) =0.16, p=0.98)—neither group was working more than the other.

Study Time:

A related factor to number of credits taken and number of hours worked is that of number of hours spent studying. Students were asked to list how much time outside of class they expected to spend on this class. Any differences in this question could lead to differences in achievement and differences in attitudes. Students who expect to work more hours on the course may receive higher grades than those who spend less time. And underestimating the amount of

Table 3.14
Expected Study Time by Treatment

Amount of time spent studying	Computer treatment (N=198)	Traditional treatment (N=179)
Less than 2 hours per week	1	1
2-5 hours per week	52	44
6-10 hours per week	104	106
10-15 hours per week	30	21
More than 15 hours per week	11	7

time needed to get a good grade may make students respond less favorably on course evaluations. The responses of the two treatment groups were compared on this question. Table 3.14 shows the results of this question. The first two categories were combined to form one category of "Less than 6 hours per week," so that the χ^2 test could be performed. The non-significant results of the test (χ^2 (3)=2.20, p=0.53) suggest that there is no difference in how the two treatment groups answered the question.

Grade Point Average:

Other variables can also be expected to have an effect on the results of this study. A student's Grade Point Average (GPA) is a measure of their past academic success, ability and their academic commitment. Previous GPA can predict future success in courses (Keith, 1990). Thus, if there are differences

Table 3.15
Distribution of GPA (at the Univ. of Minn.) by Treatment

	Computer treatment (N=197)	Traditional treatment (N=178)
No GPA at UMN	95	94
3.4-4.0	44	40
2.8-3.3	44	25
1.8-2.7	13	18
1.7 and below	1	1

in GPA among the two groups, these differences may be part of any differences in results seen between the two treatments. Table 3.15 shows the distribution of Grade Point Averages for the two treatment groups.

To test the hypothesis that the college grade point average was the same for the two treatment groups, the last two categories were combined to form one category of GPA "2.7 and below." The two groups show no significant difference on this question (χ^2 (3) =5.24, p=0.16). Another test was performed to examine any possible differences among only those students who did have a GPA at the University of Minnesota. This test also showed no significant differences (χ^2 (2) =4.47, p=0.11). The two groups do not appear to have different grade point averages.

Prior physics and mathematics:

Previous physics and math backgrounds can also cause differences in attitudes and achievement among students. A student who has had no physics before would not be as likely to do as well as a student who has taken high school or college physics already. Students who are repeating a course may do better than those seeing this material for the first time. Previous exposure to physics may also affect attitudes towards a course. A student who took physics in high school may expect their college physics course to be the same, and they may be upset in finding out that it is not. Or they may be very pleased with the course because they understand the material better the second time through. Likewise, a student with no previous physics may appreciate the class for what they are learning, or they may be disappointed because the class was different from their expectations. For these reasons, it is important to examine the previous physics background of the students in the two treatments.

Given this information, a χ^2 test shows no significant difference between the two groups (χ^2 (3) =0.72, p=0.87). Neither group has had more physics than the other has.

Table 3.17 shows the number of students repeating this physics course. Because of the small numbers of students who have repeated this course, this data does not meet the requirements for the χ^2 test. An inspection of the data shows that there are no differences in the numbers of students who are repeating this course—nearly all of the students are taking this course for the first time.

Table 3.16

Previous Physics Taken by Treatment

	Computer treatment (N=198)	Traditional treatment (N=180)
No previous physics	17	17
Yes, in high school	167	151
Yes, in college	6	7
Yes, in both college and high school	8	5

Table 3.17

Repeating this Course? by Treatment

	Computer treatment (N=198)	Traditional treatment (N=180)
Never taken this course	194	174
Taken this course at UMN	4	2
Taken this course elsewhere	0	4

Students in this calculus-based physics course were expected to have already taken calculus, or to be registered in a calculus course concurrently with this physics course. A student's math background may affect how well they would do in a course. A student who has learned calculus before taking physics would be better prepared when they encounter calculus in their physics course than a student who is learning the calculus concurrently with seeing it in physics. It is also possible that some students have less math background before entering their calculus course, which could make learning the calculus more difficult.

Table 3.18

Last High School Math Class Taken by Treatment

	Computer treatment (N=196)	Traditional treatment (N=179)
Algebra	1	5
Geometry	0	1
Trigonometry	11	10
Pre-calc, Functions, or Analysis	56	39
Calculus	118	117
Other, more advanced math	10	7

Information on students' math background is summarized in Table 3.18, Table 3.19, and Table 3.20.

To compare high school math among the two groups, the first three categories were combined to one category: "Algebra, Geometry, and Trigonometry." The χ^2 test showed no significant difference between computer-users and non-computer-users (χ^2 (3)=3.38, p=0.34).

Another question of interest is to compare how many students in each group took calculus in high school. Table 3.19 summarizes this information.

Table 3.19

High School Calculus by Treatment

	Computer treatment (N=196)	Traditional treatment (N=179)
No calculus	68	55
Calculus	128	124

Table 3.20a

Last College Math Class Taken by Treatment

	Computer treatment (N=197)	Traditional treatment (N=178)
No college math	82	91
Algebra	0	1
Geometry	0	0
Trigonometry	2	1
Pre-calc, Functions, or Analysis	10	4
First-quarter calculus	27	18
Second-quarter calculus	27	24
Third-quarter calculus	28	26
Multivariable calculus	15	9
Other, more advanced math	6	4

There is no significant difference on taking calculus in high school for the two groups (χ^2 (1)=0.67, p=0.41).

Table 3.20b

Last College Math Class Taken by Treatment

	Computer treatment (N=197)	Traditional treatment (N=178)
No college math	82	91
Algebra, Geometry, Trigonometry, Pre-calc, Functions, or Analysis	12	6
First-quarter calculus	27	18
Second-quarter calculus	27	24
Third-quarter calculus	28	26
Multivariable calculus	15	9
Other, more advanced math	6	4

Table 3.20a shows the last college math class taken for the two sets of students.

To test the hypothesis that the two groups have equivalent college math backgrounds, the second, third, fourth, and fifth categories were combined, as shown in Table 3.20b.

The χ^2 test shows no significant differences between the groups (χ^2 (6)=5.47, p=0.49). A test on only those who have taken a college math class also showed no significant difference (χ^2 (5)=2.11, p=0.83). The two groups appear to be equivalent in physics and math backgrounds.

Table 3.21

Self-reported Computer Literacy by Treatment

	Computer treatment (N=198)	Traditional treatment (N=179)
Uncomfortable with computers	9	7
Marginally computer literate	30	36
Fairly computer literate	84	82
Very computer literate	45	42
Extremely computer literate	30	12

Computer Literacy:

Because this study involved the use of computers, another variable of interest is computer literacy. Students were asked to report their estimate of their own computer literacy. If one set of students were more computer literate than the other set, this could affect how well they would work with the computers and their attitudes towards the computers. Table 3.21 shows the results of students' reporting their computer literacy.

The χ^2 test indicated that there is no significant difference in computer literacy for the two treatment groups at the 0.003 level (χ^2 (4)=7.70, p=0.10).

Feeling of preparation:

Students were also asked to report how well prepared they felt for this

Table 3.22

Feeling of Preparedness for Course by Treatment

	Computer treatment (N=197)	Traditional treatment (N=180)
Totally unprepared	4	11
Unprepared	10	12
Somewhat prepared	58	60
Prepared	87	77
Very well prepared	38	20

class. Differing feelings of preparation could lead to different attitudes towards the course, as well as leading to different levels of achievement. Table 3.22 summarizes the data on feelings of preparation.

The two treatment groups did not differ significantly (at the 0.003 level) on how well prepared they felt for this class ($\chi^2(4)=8.93$, $p=0.06$).

Expected grade:

A factor similar to preparedness is the grade students expect to receive in a course. Students who expect to receive a higher grade may work harder than those who expect a lower grade. Expectations of grades might also cause changes in students' attitudes; if a course were more difficult than a student expected, he or she might not rate the class as favorably as a student who expected a more difficult class.

Table 3.23a

Distribution of Expected Grade in this Course by Treatment

	Computer treatment (N=197)	Traditional treatment (N=178)
A	145	106
B	49	68
C	2	4
D	1	0
F	0	0

Table 3.23b

Expected Grade in this Course by Treatment

	Computer treatment (N=197)	Traditional treatment (N=178)
A	145	106
B or lower	52	72

Table 3.23a shows the grades expected by the two groups of students. To test for any possible differences, the last four grades were combined, giving Table 3.23b.

This table suggests that more of the students in the computer treatment expected to get an A grade, but this is not supported by the statistical test (χ^2 (1)=8.34, p=0.004). There is no significant difference between the grades the two groups expected to receive in this course, at the 0.003 level. However, with a probability of 0.004, this data should be kept in mind.

Pretest scores on conceptual tests:

Just as information on the two groups can be determined from the demographics questionnaire, other information can be found by examining the scores of the two groups on the two conceptual tests given in the first week of class. These two conceptual tests measure understanding of physics in two broad areas: the Force Concept Inventory (Hestenes, Swackhamer, and Wells, 1992) measures students' understanding of forces, and the Test of Understanding Graphs-Kinematics (Beichner, 1994) measures students' ability to understand and translate various kinematics graphs. These tests were given together with the demographics questionnaire during the first lab session.

Table 3.24 shows the results of the pretests for both the computer treatment and the traditional treatment.

Table 3.24
Conceptual Test Pretest Results by Treatment

Test		Computer treatment	Traditional treatment
FCI pretest	N	200	181
	Mean (30 possible points)	14.1	13.3
	St. Dev.	6.5	5.2
	St. Error	0.46	0.39
TUG-K pretest	N	200	181
	Mean (21 possible points)	12.0	10.8
	St. Dev.	5.3	4.6
	St. Error	0.38	0.34

Examining the results of the two tests indicated that the students in the computer treatment scored higher on the pretest for both the FCI and the TUG-K. A two-tailed t-test on the FCI pretest scores indicated no significant difference between the computer treatment pretest and the traditional treatment pretest (t (379)=1.20, p=0.22). A two-tailed t-test on the TUG-K pretest scores indicated that there was no significant difference (at the 0.003 level) between the pretest scores of the two groups of students (t (379)=2.25, p=0.02). The students in the computer treatment scored as well on the pretest as the students in the traditional treatment.

Summary:

The two treatment groups had no significant differences on fifteen background variables.

The design of the study had the 27 lab sections split evenly among the three lecture sections, which reduced possible instructor effects. It is not possible to run tests on the background variables by instructor due to the low numbers of students in the cells. Since the two groups are quasi-equivalent as shown, any possible pretest differences within instructor must be minimal. This is supported by examining the gain scores on the two conceptual tests of the two treatments by instructor. Table 3.25 lists the gain scores and standard errors for the two treatments and the three instructors. The two groups will be considered equal as whole groups, and instructor effects will not be considered in later analysis.

Given these results, the two treatment groups can be considered equivalent groups for the subsequent analyses.

Table 3.25

Gain Scores on Conceptual Tests by Treatment and Instructor

Test	Instructor		Computer Treatment	Traditional Treatment
FCI	A	N	59	40
		Mean	6.7	7.1
		St. Error	0.5	0.7
	B	N	62	51
		Mean	7.3	8.3
		St. Error	0.5	0.5
	C	N	51	73
		Mean	6.6	7.9
		St. Error	0.6	0.5
TUG-K	A	N	59	40
		Mean	4.1	3.7
		St. Error	0.5	0.5
	B	N	62	51
		Mean	3.9	4.0
		St. Error	0.4	0.6
	C	N	51	73
		Mean	2.7	4.4
		St. Error	0.4	0.4

Achievement:

To measure achievement, two conceptual tests were given to the students, and course grades were collected for each student. Because there were three instructors within each of the groups, the scale used to calculate grades varied within the groups. To remove this difference, the grades for each class were converted to z-scores. This conversion made each of the three classes' distributions have a mean of zero and a standard deviation of 1. Once the z-scores were computed, the three classes could be combined without differences in variances or means.

The three measures of achievement were analyzed together using a statistical procedure called a multivariate analysis of covariance (MANCOVA). (See Grimm & Yarnold, 1995 for a discussion of multivariate analysis.) As one does more statistical tests on data, it is more likely that one of the tests will appear significant due to chance. On any test, you typically may say that there is only a 5% chance that this test would be significant due to random factors. If you were to perform 100 tests, that 5% means that 5 of those 100 tests would turn out significant just due to chance. This is called the Type I error in an experiment. A MANCOVA test looks at all your measures together to take into account an added possibility of getting a significant result due to chance, reducing the chances of making a Type I error. This is the “multivariate” part of the multivariate analysis of covariance.

The second part of the MANCOVA is analysis of covariance. Covariates are independent variables that could lead to differences among your dependent variables. In this study, it would be expected that a student’s pretest score on a conceptual test could partially predict that student’s posttest score (the dependent variable). But we are not interested in how the pretests affect the posttests for this study. Thus the pretest scores can be considered covariates. The analysis of covariance takes into account the covariates—it factors out any effect that the covariates have on the dependent variables.

Another way of taking the pretest scores into account would be to use gain scores (post-test – pretest) as the dependent variable instead of post-test scores. Campbell and Stanley (1963) suggest that covariance is a preferable method to using gain scores, as it is a more precise way of accounting for pretest variance. For this analysis, the pretest scores on both conceptual tests were labeled as covariates. The MANCOVA test factored out any possible effect due to differences in pretest.

Two choices were available as units of analysis: students or sections. Students were used as the unit of analysis because this gave the MANCOVA more power to detect any differences that exist among the groups. There were about 350 students and 27 lab sections. A MANCOVA test requires many degrees of freedom. If sections were used, the MANCOVA would lose too much of its power to detect differences, and the Type II error is increased. This is not a problem when using students as the unit of analysis. One difficulty with using students, however, is that tests of heterogeneity of variance on the pretest scores of the computer and traditional treatment groups showed that the computer group and the traditional group had different variances in their scores (Levene's test of homogeneity of variance, $p=0.001$ for the FCI pretest and $p=0.47$ for the TUG-K pretest). But the MANCOVA test is generally considered robust in the face of heterogeneity of variance (e.g., see the discussion in Weinfurt, 1995). The major assumption of the MANCOVA test is homogeneity of the covariance matrices, and the data met this assumption (Box's M test (18,112708)=17.3, $F=.942$, $p=.53$).

To run the MANCOVA, the SPSS statistical package was used. SPSS offers four different test statistics: Pillai-Bartlett's trace V, Hotelling-Lawley's trace T, Wilks's likelihood ratio W, and Roy's largest root R. Stevens (1986) reviewed the literature and concluded that the choice of test statistic will not make a major difference. Olson (1979) argues that Pillai-Bartlett's trace is the most robust and the most powerful, so the Pillai-Bartlett trace was used for this analysis.

The software used was the SPSS General Linear Model Multivariate Analysis program. The model used was Type III, which is for unbalanced models with no empty cells. This model takes into account all effects that are not included in the effects being considered. There were two *a priori* comparisons in the research questions: one looking at a treatment main effect, and the other looking at a gender-treatment interaction. In order to control for Type II error, one test was run, including the treatment main effect and the gender-treatment interaction and nothing else in the model.

<u>Attitudes:</u>

The second research question asked about students' overall attitudes towards the course and the particular tools used in the laboratory. To get information on students' attitudes, several questions about the course and the lab tools were asked on a post-course evaluation questionnaire. Because we are not interested in particular aspects of the attitude, the questions were analyzed together as an overall attitude measure.

Because there were so many questions, a factor analysis (Bryant & Yarnold, 1995) was used to help determine how to analyze the data. A factor analysis examines responses to a set of questions and determines which questions link up with other questions: if students answered a certain way on one question, did they answer similarly on other questions? The factor analysis can pull out “factors”: sets of questions that go together, measuring the same thing.

The nine questions about attitudes towards the three components of the course could be argued as having one factor—general attitude toward the course, or they could have three factors: one for each component of the course. The six questions about attitude toward the lab tools could have one factor, or they could be testing more than one thing. A factor analysis determines which questions should be analyzed together. By testing which questions are measuring the same thing, the analysis of the questions becomes more powerful. By reducing the questions that do not contribute to a measure of the students’ attitudes, the “noise” in the data is reduced. This is reducing Type II error.

Table 3.26

Factor Loadings and Eigenvalues for Attitude Towards Course Questions

Question	Factor 1	Factor 2	Factor 3
1. Lectures were a waste of time.		0.85	
2. Lectures helped clarify ideas in the text.		0.86	
3. The main points of the lecture were clearly stated and emphasized.		0.78	
4. Solving problems with my group helped me to understand the course material.			0.87
5. The discussion sessions were a waste of time.			0.83
6. The discussion problems provided useful guidance for solving problems on the individual exams.			0.60
7. The laboratory problems provided useful guidance for solving problems on the individual exams.	0.77		
8. The laboratory problems helped me to understand the concepts covered in class.	0.89		
9. The laboratory sessions were a waste of time.	0.81		
Eigenvalue	3.38	1.71	1.20

Attitude Toward the Course:

The factor analysis showed three different factors for each of the three components of the course. The Scree plot indicated three factors, as did the eigenvalues. Table 3.26 shows the factor loadings of each question for the three factors and the eigenvalues of the three factors. Loadings of less than 0.3 were not included. The total variance explained by Factor 1 was 38%, by Factor 2 was 19%, and by Factor 3 was 13%, giving a total variance explained of 70%.

Table 3.27

Factor Loadings and Eigenvalues for Attitude Towards Lab Tools Questions

Question	Factor 1
1. Although it took time to learn to use spark tape (VideoTool), it was time well spent.	0.72
2. Analyzing spark tape data and Polaroid film (Using VideoTool) taught me the importance of selecting an appropriate origin and / or axis and meaningful units in solving problems.	0.78
3. Analyzing spark tape data (Using VideoTool) helped me understand the equations I used in class.	0.83
4. Analyzing spark tape data (Using VideoTool) helped my understanding of derivatives.	0.77
5. I found doing the data analysis in lab with my group (I found the printed graphs and equations) useful in writing my lab reports.	0.55
6. I am looking forward to using spark tapes / Polaroid film (VideoTool) in my next physics class.	0.72
Eigenvalue	3.23

The three factors matched up perfectly with the three components of the course. Students' responses to the nine questions indicated that they felt differently toward the three components of the course.

Attitude Toward the Lab Tools:

For the six questions about the laboratory tools, the factor analysis pulled out one factor. Table 3.27 lists the eigenvalue and factor loading of each of the questions for the single factor. The total variance explained by this one factor was 54%. Students responded similarly to all six questions, which suggested that these questions were measuring an overall attitude toward the lab tools.

The factor analyses led to four different groups of questions: one for lecture, one for lab, one for discussion session, and one for lab tools. These four groups of questions were analyzed using the same method described below. Because four tests are being run examining attitude by treatment, the level of significance for each test is reduced by 4, from 0.05 to 0.0125. This controls for Type I error.

To get an overall measure of attitude, the numbers of students responding positively to each attitude question were counted. Since the possible responses for each question are Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree, the cut-off point for positive responses needed to be decided. When concerned about creating negative attitudes in a course, it makes sense to count those responses which are not negative as "wins." A neutral response is a good response for this situation, so it was counted with the Agree and Strongly Agree responses. From this criteria, a table of positive responses for each question can be created, with one column for the experimental group and one column for the control group. A χ^2 test on the categorical data will determine if there are any differences between the two groups; i.e., if the two groups show any differences on overall attitude towards the course.

Group Behavior:

The two methods used to study group behavior were observations and survey questions.

Observation Data:

Many observations were made of the students solving the lab problems. Every piece of data from the coding sheets was entered into a spreadsheet program. The data are easily transformed into counts for each of the categories of interest. By combining the data from all observations of the computer treatment groups, and by doing the same for the traditional treatment groups, an overall summary of both groups can be created. This summary gives the total number of observed minutes, the total number of minutes spent talking about physics, talking about analysis, talking about equipment, etc. The summary data from the two groups can be compared by using a χ^2 test.

Group functioning questions:

Nine questions were given to the students which asked about how their group interacted. The research question asked about whether or not perceived group functioning differed between the groups. To answer this question, the same procedure was used as when analyzing the attitude questions. A factor analysis was run to determine how to group the questions for analysis, and then the groups of questions were analyzed using a χ^2 test.

Table 3.28

Factor Loadings and Eigenvalues for Group Functioning Questions

Question	Factor 1	Factor 2
1. Our group discussed equipment difficulties.		0.83
2. Our group discussed misunderstandings about the physics.		0.78
3. One person in our group did most of the data analysis.	-0.57	
4. I felt I was contributing to our group's solution to the lab problem.	0.48	
5. Our group worked efficiently.	0.69	
6. I felt the other members of our group were contributing to the solution to the lab problem.	0.76	
7. Our group did most tasks together.	0.70	
8. Our group divided most tasks.		
9. Our group communicated well with each other, so each member understood what the heck was going on.	0.71	
Eigenvalue	2.76	1.27

The factor analysis on the nine group functioning questions pulled out two factors. Table 3.28 lists the eigenvalues and the factor loadings for the nine questions. The first factor includes questions 3, 4, 5, 6, 7, and 9. These are all "activity" questions—things a group did. The second factor includes questions 1 and 2: "discussion" questions. Question 8 did not load highly on any factor, which means that it was not measuring the same thing that the other eight questions were. Factor 1 explained 31% of the variance, and Factor 2 explained 14% of the variance, so a total of 56% of the variance was explained by using the two factors.

To analyze the data, question 8 will be thrown out, since it is only contributing to the “noise” of the analysis, and the Type II error will be reduced by eliminating this question. The other questions will be analyzed in two groups: questions 1 and 2 in one group, and the other six questions in another group.

Once the grouping of the questions was decided, the next step was to determine how to gather the overall group functioning information. Possible responses to the group functioning questions include: Hardly Ever, Not Very Often, Sometimes, Quite Often, and Almost Always. The number of students answering Quite Often and Almost Always were combined, since these two responses indicate that the particular event was definitely happening in the group. The response Sometimes was not included since it did not indicate that the event was definitely and often occurring in the group, and the concern was for events that were definitely happening.

A table of Quite Often and Almost Always responses for each question will be formed, and a χ^2 test will be run to determine if there are any differences in how the experimental group and the control group perceive their group functioning.

Gender-Treatment Interactions:

To analyze questions of interactions of gender and treatment, similar methods were used as those used to look for main effects of computer tool use. To determine if there was an interaction between gender and treatment in terms of achievement, the factor of gender was included in the multivariate analysis of covariance (MANCOVA). This test looks for any interactions between gender and treatment for the three measures of achievement. The two conceptual test pretest scores are included as covariates.

To test for interactions by gender on students' attitudes, the numbers of women and men responding Neutral, Agree, and Strongly Agree were added together for the groups of questions determined above. A χ^2 test was run comparing the women in the computer treatment to the women in the traditional treatment. A similar test was run comparing the men in the two treatments. Then two tests were run comparing the computer treatment men and women, and comparing the traditional treatment men and women. By examining the results of the four tests and looking for differences between the results, any possible interaction by gender can be found. The level of significance used was reduced by the number of tests being done, which led to an α of $0.05/16=0.003$.

The same method was used to look for possible gender interactions on perceived group functioning. The number of women and men responding Quite Often and Almost Always were added, and χ^2 tests run comparing the two sets of women, the two sets of men, the two computer treatment groups, and the two traditional treatment groups. By looking at the results of the four tests, the question of gender-treatment interaction can be answered.

Summary

This study examined the effect of introducing a computer data collection and analysis tool (VideoTool) into a physics problem-solving laboratory. Using a two-sample, pre-post and observation design, differences between computer users and non-computer users could be studied on measures of achievement, attitude, and interactions. Conceptual tests and course grades were used to study achievement, and a survey was given to examine attitudes. Observations and survey questions were used to study group behaviors. With these methods, this study can examine some of the effects of adding VideoTool to a problem-solving laboratory.

Chapter 4 Results

The main point of this study was to determine the results of adding computer tools to a physics problem-solving laboratory. Various measures were used to determine different effects on students: tests and grades to measure achievement, surveys to measure attitudes, and observations to measure behavior.

This chapter will present the results of this study in several sections. The first section presents the results of the first research question: examining the achievement of the students in the computer treatment and students in the traditional treatment. The second section will summarize the results of the second research question: how does using the computer tool affect students' attitudes. The third section will discuss the third research question: how using the computer tool affected the ways students solved the laboratory problems. The fourth section will discuss the gender-treatment interactions for achievement, attitude, and group functioning.

Achievement

The first research question examined students' achievement:

1. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change students' achievement?

a. Do students in problem-solving laboratories with VideoTool (experimental treatment) gain equally well as students in problem-solving laboratories with traditional tools (control treatment) on a test of understanding kinematics?
b. Do students in the two treatments gain equally on a test of understanding force?
c. Do students in the two treatments do equally well on overall course grades?

One of the biggest concerns that arises when introducing change into a well run course is that by changing things you may damage those parts that are working well, thereby reducing the effectiveness of the course instead of improving it. This is of special concern when implementing new computer tools as was done for this study. The research literature is ambivalent about how computers may affect students' achievement. In this study, the computer tool was added to an existing course structure and a particular pedagogy. All of the laboratory problems were designed for the traditional non-computer instruments. Since these problems were not changed to take advantage of what the computer tool was capable of, there was significant concern that adding the computer tool to the laboratory would cause a decrease in achievement. The null hypothesis was that there would be no effect on achievement. To look for any possible adverse effects from the new computer tool, the final course grades were examined. Two conceptual tests were also given at the end of the course as another measure of how well students had learned certain areas of physics. The results of these measurements were analyzed using a multivariate analysis of covariance test (MANCOVA). The question of interest is the possibility of a treatment main effect on achievement, not any possible pretest differences (these are entered as covariates and are taken into account).

Table 4.1 summarizes the data from the three different measures of achievement: Force Concept Inventory post-test, the Test of Understanding Graphs-Kinematics post-test, and the final course grade, listed as a z-score.

The FCI post-test, the TUG-K post-test, and the course grade were entered as dependent variables in the SPSS MANCOVA program. The FCI pretest and the TUG-K pretest were entered as covariates. Treatment and gender were entered as factors. The model chosen included treatment and gender main effects (are there any significant differences among the computer-users or non-computer-users), and a treatment by gender interaction (do men and women differ in the two treatments). The assumption of homogeneity of covariance matrices was satisfied (Box’s M test (18,112708)=17.3, F=.942, p=.53).

The overall MANCOVA test was significant. For the treatment main effect, the Pillai’s trace F (3,329)=2.9 was significant, p=0.035. Because the overall MANCOVA test was significant, the next step was to examine each of the three measures to determine where the significance arises.

Table 4.1

Achievement Results by Test and Treatment

Test		Computer treatment	Traditional treatment
FCI	N	172	164
	Mean (Adjusted mean)	20.8 (19.5)	21.2 (20.9)
	St. Dev.	6.1	5.2
TUG-K	N	172	164
	Mean (Adjusted mean)	15.7 (15.1)	15.0 (15.0)
	St. Dev.	4.1	4.0
Course Grade	N	172	164
	Mean (Adjusted mean)	.136 (.034)	.029 (.074)
	St. Dev.	.948	.920

For the FCI post-test, the F test was significant ($F(1,331)=7.2$, $p=.008$). The η^2 (eta-squared) value was 0.02. An η^2 value gives a sense of how much variance in the distributions is explained by the model chosen. It is similar to a correlation coefficient r^2 for linear relationships. Cohen (1977) suggests that for η^2, a value of .02 is a very small correlation. The data for the FCI test indicate that the students in the traditional treatment did better on the FCI post-test than students in the computer treatment. However, this result only explains 2% of the variation in the scores.

For the TUG-K post-test, the F-test was not significant ($F(1,331)=0.05$, $p=0.83$). The course grade also showed no significant difference ($F(1,331)=0.15$, $p=0.70$). There were no significant differences between the two treatments on TUG-K post-test and overall course grades.

Summary:

There was a significant difference in achievement for students in the computer treatment and students in the traditional treatment. Students in the traditional treatment group did slightly better on the FCI post-test. There were no significant differences for TUG-K post-test or overall course grades.

Attitude

The second research question was concerned with students' attitudes:

2. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change students' attitudes?
   a. Do students in problem-solving laboratories with VideoTool (experimental treatment) have the same overall attitude towards the course as students in problem-solving laboratories with traditional tools (control treatment)?
   b. Do students in the two treatments have the same attitude towards using the specific computer or non-computer tools used in the laboratory?

To determine if use of the computer tool affected students' attitudes towards the course and the laboratory, student responses to fifteen survey questions were analyzed. Four groups of questions were used: attitude towards the three components of the course, and attitude towards the particular laboratory tools used. Because four tests were used, the level of significance for each test was reduced by 4, giving an α of $0.05/4=0.0125$. The complete distributions of student responses are given in Appendix G.

Attitude towards the overall course:

To analyze students' attitudes towards the three components of the course, the number of students responding positively to three questions was gathered in a table. A χ^2 test was performed to determine if there were any differences in overall attitude. Tables 4.2, 4.3, and 4.4 list the percentage of students in the computer and traditional treatments who answered Strongly Agree, Agree, or Neutral to the nine attitude questions about the three components.

Table 4.2

Percentage Responses to Lecture Attitude Questions by Treatment

Question	Computer treatment (N=173)	Traditional treatment (N=168)
1. Lectures were a waste of time.	56*	64*
2. Lectures helped clarify ideas in the text.	72	63
3. The main points of the lecture were clearly stated and emphasized.	65	62

* Percentage of students answering Neutral, Agree, and Strongly Agree

Table 4.3

Percentage Responses to Discussion Session Attitude Questions by Treatment

Question	Computer treatment (N=173)	Traditional treatment (N=168)
4. Solving problems with my group helped me to understand the course material.	83*	83*
5. The discussion sessions were a waste of time.	38	39
6. The discussion problems provided useful guidance for solving problems on the individual exams.	73	73

* Percentage of students answering Neutral, Agree, and Strongly Agree

Table 4.4

Percentage Responses to Laboratory Attitude Questions by Treatment

Question	Computer treatment (N=173)	Traditional treatment (N=168)
7. The laboratory problems provided useful guidance for solving problems on the individual exams.	54	51
8. The laboratory problems helped me to understand the concepts covered in class.	77	77
9. The laboratory sessions were a waste of time.	43	48

* Percentage of students answering Neutral, Agree, and Strongly Agree

Table 4.5

Percentage Responses to Laboratory Tools Attitude Questions

Question	Computer treatment (N=171)	Traditional treatment (N=168)
1. Although it took time to learn to use spark tape (VideoTool), it was time well spent.	81*	70*
2. Analyzing spark tape data and Polaroid film (Using VideoTool) taught me the importance of selecting an appropriate origin and / or axis and meaningful units in solving problems.	70	77
3. Analyzing spark tape data (Using VideoTool) helped me understand the equations I used in class.	62	74
4. Analyzing spark tape data (Using VideoTool) helped my understanding of derivatives.	52	57
5. I found doing the data analysis in lab with my group (I found the printed graphs and equations) useful in writing my lab reports.	83	86
6. I am looking forward to using spark tapes / Polaroid film (VideoTool) in my next physics class.	79	43

* Percentage of students answering Neutral, Agree, and Strongly Agree

Lecture: The χ^2 test (χ^2 (2)=0.14, p=0.93) shows that there is no statistically significant difference in how the two treatment groups felt about the lecture component.

Discussion Session: The χ^2 test (χ^2 (2)=0.007, p=0.99) shows that there is no statistically significant difference in how the two treatment groups felt about the discussion session component.

Laboratory: The χ^2 test (χ^2 (2)=0.20, p=0.90) shows that there is no statistically significant difference in how the two treatment groups felt about the lab component.

Attitude Towards the Particular Laboratory Tools:

A similar analysis was performed on six questions asking students about their attitude towards the particular tools they used in the laboratory. Table 4.5 lists the percentage of students in the two groups who answered Strongly Agree, Agree, or Neutral to these questions about the laboratory tools.

A χ^2 test on this data resulted in no significant difference at the 0.0125 level ($\chi^2(5)=25.43$, $p=0.044$). Though the overall difference is not significant, there is a notable difference in the response to the last statement. The students who used VideoTool were much more likely to agree to this statement.

Summary:

The computer and traditional treatment groups did not differ in their attitude towards the three components of the course or in their attitude toward the particular lab tools.

Group Behavior

The third research question focused on group behaviors while solving the lab problems:

3. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change students' how groups solve the laboratory problem?

a. Do groups in problem-solving laboratories with VideoTool (experimental treatment) spend the same amount of time in each part of the laboratory as groups in problem-solving laboratories with traditional tools (control treatment)?

b. Do groups in the two treatments talk about the same things while solving the laboratory problems?

c. Do students in the two treatments perceive their group functioning differently?

To determine how students solved the laboratory problem in their groups, two methods were used. The first was to observe many different groups as they solved the laboratory problems. Two tests were used to determine differences in behavior, and the level of significance for each test was 0.05/2=0.025. The second method was to ask students about their perceived group functioning on a post-course questionnaire. The results from both of these methods are given below.

What Do Groups Spend Their Time on in Lab:

The first research question on group behavior asked if there was any

Table 4.6

Percentage of Time Spent in Different Parts of the Lab by Treatment

	Computer treatment (N=45 groups)	Traditional treatment (N=34 groups)
Exploration	20.4	24.3
Measurement	23.7	30.5
Analysis	55.9	45.2

Table 4.7

What Groups Talk About While Solving the Lab Problem by Treatment

	Computer treatment (N=45 groups)	Traditional treatment (N=34 groups)
1. Talking physics	5.7	6.4*
2. Taking data	10.2	11.9
3. Exploring	9.6	12.1
4. Analysis	31.9	22.8
5. Equipment	8.1	8.4
6. Group management	0.4	0.6
7. Task management	15.4	14.2
8. Social / off-task	9.5	9.7
9. Talking with TA	9.2	14.0

* Percentage of total time spent solving the lab problems

difference in what students were spending their time on while solving the lab problems: exploration, measurement or analysis. To answer this question, the data from all 45 computer group observations and 34 non-computer group observations were combined. A total number of observed minutes were counted, and the total number of minutes spent in each of the main parts of the lab (Exploration, Measurement, and Analysis) were counted. A total percentage of time spent in each of the three parts was found for the computer groups and the non-computer groups, and this data was entered into a table. A χ^2 test was run to find any differences that might exist between the groups. The data are found in Table 4.6.

There is no significant difference between how much time the two groups spend on each part of the laboratory (χ^2 (2)=2.35, p=0.31).

<u>What Groups Talk About:</u>

Data on what the groups were talking about was collected for every minute the groups were observed. The total percentage of time spent talking about each possible topic was collected for the computer and the traditional treatment groups. These data were combined into Table 4.7.

To analyze these data, the group management code was combined with the task management code, so that the assumptions of the χ^2 test would be fulfilled. The χ^2 test revealed no significant differences in what the two groups spent their time talking about. (χ^2 (7)=3.01, p=0.88.)

<u>How Students Perceive their Group Functioning:</u>

The other method of determining whether or not VideoTool changed how the group solves the problem was to ask the students to rate their perceived group functioning. Nine questions on different aspects of group functioning

Table 4.8

Responses to Perceived Group Functioning Questions—“Activity” by Treatment

	Computer treatment (N=173)	Traditional treatment (N=168)
3. One person in our group did most of the data analysis.	27	17
4. I felt I was contributing to our group’s solution to the lab problem.	75	77
5. Our group worked efficiently.	55	58
6. I felt the other members of my group were contributing to the solution of the lab problem.	72	80
7. Our group did most tasks together.	67	71
9. Our group communicated well with each other, so each member understood what the heck was going on.	67	64

* Percentage of students answering Quite Often and Almost Always

Table 4.9

Responses to Perceived Group Functioning Questions—“Discussion” by Treatment

	Computer treatment (N=173)	Traditional treatment (N=168)
1. Our group discussed equipment difficulties.	32*	53
2. Our group discussed misunderstandings about the physics.	48	39

* Percentage of students answering Quite Often and Almost Always

were given to students at the end of the course. The questions were analyzed in two groups: Questions 1 and 2 were “discussion” questions, and Questions 3, 4, 5, 6, 7, and 9 were “activity” questions. Question 8 was not used in the analysis. Since two tests were run, the level of significance was $\alpha=0.05/2=0.025$. The complete distributions of student responses are given in Appendix G.

For the six “activity” questions the percentage of students answering that each activity occurred Quite Often or Almost Always are listed in Table 4.8.Results of the χ^2 test showed no significant differences between how the two treatment groups perceive their “activity” group functioning (χ^2 (5)=2.72, p=0.74).

Table 4.9 shows the percentage of students answering the two “discussion” questions. There was a significant difference in perceived “discussing” group functioning between the two groups (χ^2 (1)=5.25, p=0.022). All four cells contribute about equally to the total χ^2 value. The students in the traditional treatment answered that their group discussed equipment difficulty more often than students in the computer treatment. The students in the computer treatment answered that their groups discussed misunderstandings about the physics more often than students in the traditional treatment.

<u>Summary:</u>

There were no significant differences in how replacing traditional tools with VideoTool affected how students solved the lab problem. Groups in the two treatments spent the same amount of time in each part of the lab, and they talked about the same things while solving the lab problem. Students in the two treatments did not differ in how they perceived their group to function in terms of “activity.” However, the treatment groups did differ on how much time was spent in their groups discussing physics or equipment difficulties.

Gender

The last research question is concerned with how use of the tools is related to gender:

4. Are there any gender-treatment interactions?
   a. Is there a gender-treatment interaction for the three measures of achievement?
   b. Is there a gender-treatment interaction for students' attitudes towards the overall course and towards the particular laboratory tools?
   c. Is there a gender-treatment interaction for how students perceive their group functioning?

There is evidence that women have fewer experiences with computers than men. It is reasonable to expect that gender may play a large part in how the use of the computer tools affects students. Given these concerns, interactions by gender were examined for achievement, attitude, and perceived group functioning.

Achievement:

To test for any gender interaction in student achievement, the variables of gender and treatment were included on a MANCOVA test. Possible gender-treatment interactions were examined.

Table 4.10 shows the results of achievement broken up by treatment and gender. On the overall test, the interaction of gender by treatment was not significant: Pillai's trace F (3,329)=1.2, p=0.32. There is no interaction between gender and treatment for the three measures of achievement.

Attitudes:

To test for possible gender-treatment interactions in students' attitudes, first the women in the two treatments were compared to each other, and then the men in the two treatments were compared to one another. Next, the women and men in the computer treatment were compared, and finally the women and men in the traditional treatment were compared. By comparing the results of the four tests, possible interaction effects can be investigated. Because there were sixteen total tests examining gender-treatment interactions for attitude, the level of significance for each test was reduced: $\alpha = 0.05 / 16 = 0.003$.

Table 4.10

Achievement by Treatment and Gender

Test	Gender		Computer treatment	Traditional treatment
FCI	Women	N	48	45
		Mean	16.2	19.0
		St. Dev.	5.0	5.2
	Men	N	124	119
		Mean	22.5	22.0
		St. Dev.	5.5	4.9
TUG-K	Women	N	48	45
		Mean	13.5	13.7
		St. Dev.	3.6	4.0
	Men	N	124	119
		Mean	16.6	15.5
		St. Dev.	3.9	3.9
Course Grades	Women	N	48	45
		Mean	-.332	-.069
		St. Dev.	.823	.906
	Men	N	124	119
		Mean	.317	.066
		St. Dev.	.933	.926

Attitude towards overall course:

Tables 4.11, 4.12, and 4.13 show the percentage of women and men in the two treatments who answered Neutral, Agree, or Strongly Agree to nine attitude questions on the three components of the course.

In order to test for gender-treatment interactions for lecture attitude, four χ^2 tests were performed.

Comparing women to women: There were no significant differences between the two groups of women on attitude toward the lecture component (χ^2 (2)=1.44, p=0.49).

Comparing men to men: There were no significant differences between the two groups of men on attitude toward the lecture component (χ^2 (2)=0.02, p=0.99).

Comparing women and men in the computer treatment: There were no significant differences between the men and women in the computer treatment on attitude toward the lecture component (χ^2 (2)=0.70, p=0.71).

Comparing women and men in the traditional treatment: There were no significant differences between the men and women in the traditional treatment on attitude toward the lecture component (χ^2 (2)=0.96, p=0.62).

There were no significant differences among the four groups. There was no interaction between gender and treatment for attitude toward the lecture component of the course.

Discussion Session:

In order to determine if there were gender-treatment interactions for the discussion session, four χ^2 tests were performed.

Table 4.11

Percentage Responses to Lecture Attitude Questions by Gender and Treatment

Question	Women in Computer Treatment (N=48)	Women in Traditional Treatment (N=47)	Men in Computer Treatment (N=125)	Men in Traditional Treatment (N=120)
1. Lectures were a waste of time.	73*	68	70	63
2. Lectures helped clarify ideas in the text.	73	55	72	65
3. The main points of the lecture were clearly stated and emphasized.	58	60	68	63

* Percentage of students answering Neutral, Agree, and Strongly Agree

Table 4.12

Percentage Responses to Discussion Session Attitude Questions by Gender and Treatment

Question	Women in Computer Treatment (N=48)	Women in Traditional Treatment (N=47)	Men in Computer Treatment (N=125)	Men in Traditional Treatment (N=120)
4. Solving problems with my group helped me to understand the course material.	85*	77	82	86
5. The discussion sessions were a waste of time.	85	87	81	83
6. The discussion problems provided useful guidance for solving problems on the individual exams.	65	72	76	73

* Percentage of students answering Neutral, Agree, and Strongly Agree

Comparing women to women: There were no significant differences between the two groups of women on attitude toward the discussion component (χ^2 (2)=0.94, p=0.62).

Comparing men to men: There were no significant differences between the two groups of men on attitude toward the discussion component (χ^2 (2)=0.15, p=0.93).

Comparing women and men in the computer treatment: There were no significant differences between the men and women in the computer treatment on attitude toward the discussion component (χ^2 (2)=1.12, p=0.57).

Comparing women and men in the traditional treatment: There were no significant differences between the men and women in the traditional treatment on attitude toward the discussion component (χ^2 (2)=0.60, p=0.74).

There were no significant differences among the four groups. There was no interaction between gender and treatment for attitude toward the discussion component of the course.

Laboratory:

In order to test for gender-treatment interactions for lab attitude, four χ^2 tests were performed.

Table 4.13

Percentage Responses to Laboratory Attitude Questions by Gender and Treatment

Question	Women in Computer Treatment (N=48)	Women in Traditional Treatment (N=47)	Men in Computer Treatment (N=125)	Men in Traditional Treatment (N=120)
7. The laboratory problems provided useful guidance for solving problems on the individual exams.	52*	51	55	51
8. The laboratory problems helped me to understand the concepts covered in class.	77	85	78	73
9. The laboratory sessions were a waste of time.	83	85	76	81

* Percentage of students answering Neutral, Agree, and Strongly Agree

Comparing women to women: There were no significant differences between the two groups of women on attitude toward the lab component (χ^2 (2)=0.25, p=0.88).

Comparing men to men: There were no significant differences between the two groups of men on attitude toward the lab component (χ^2 (2)=.42, p=0.81).

Comparing women and men in the computer treatment: There were no significant differences between the men and women in the computer treatment on attitude toward the lab component (χ^2 (2)=0.40, p=0.82).

Comparing women and men in the traditional treatment: There were no significant differences between the men and women in the traditional treatment on attitude toward the lab component (χ^2 (2)=0.36, p=0.83).

There were no significant differences among the four groups. There was no interaction between gender and treatment for attitude toward the lab component of the course.

Since all of the twelve tests came out similarly, we can conclude that for attitude toward the three components of the course, there is no interaction by gender.

<u>Attitude towards the laboratory tools:</u>

To test for gender-treatment interactions in students' attitude towards the laboratory tools they used, a similar method was used. The women in the two treatments were compared, and the men in the two treatments were compared. Then the women and men were compared within treatment. By examining the four comparisons, possible interactions could be determined.

Table 4.14

Percentage Responses to Laboratory Tools Attitude Questions by Gender and Treatment

Question	Women in Computer Treatment (N=48)	Women in Traditional Treatment (N=46)	Men in Computer Treatment (N=123)	Men in Traditional Treatment (N=120)
1. Although it took time to learn to use spark tape (VideoTool), it was time well spent.	85	67	80	71
2. Analyzing spark tape data and Polaroid film (Using VideoTool) taught me the importance of selecting an appropriate origin and / or axis and meaningful units in solving problems.	79	78	67	76
3. Analyzing spark tape data (Using VideoTool) helped me understand the equations I used in class.	67	76	61	73
4. Analyzing spark tape data (Using VideoTool) helped my understanding of derivatives.	50	54	53	58
5. I found doing the data analysis in lab with my group (I found the printed results and equations) useful in writing my lab reports.	83	93	83	83
6. I am looking forward to using spark tapes / Polaroid film (VideoTool) in my next physics class.	83	48	78	43

* Percentage of students answering Neutral, Agree, and Strongly Agree

Women's responses to six questions about the laboratory tools can be found in Table 4.14. A χ^2 test came out non-significant at the 0.003 level (χ^2

(5)=11.9, p=0.036). The only large difference is in the response to the last question, though this difference in not significant.

The differences between the men in the two treatments are not significant (χ^2 (5)=12.6, p=0.027). As with the women's responses, the largest difference, though not significant, came from the last question.

The women and men in the computer treatment were also compared. The differences between the women and men in the computer treatment are not significant (χ^2 (5)=0.97, p=0.97). The differences between the women and men in the traditional treatment were not significant (χ^2 (5)=0.92, p=0.97). Because none of the tests on attitude toward the laboratory tools was significant, there can be no significant interaction between gender and treatment for this measure.

Attitude summary:

There were no significant differences found among the sixteen tests looking at attitude. There are no gender-treatment interactions for attitude.

Group Functioning:

The last question of interest asks if there is any gender-treatment interaction in perceived group functioning. The same method was used to look at group functioning as was used for attitudes: test the men and women separately, and compare the women and men within the two treatments, and compare the results of the four tests. The group functioning is analyzed in

Table 4.15

Responses to “Activity” Group Functioning Questions by Gender and Treatment

	Women in Computer Treatment (N=48)	Women in Traditional Treatment (N=47)	Men in Computer Treatment (N=125)	Men in Traditional Treatment (N=120)
1. One person in our group did most of the data analysis.	21	11	29	20
2. I felt I was contributing to our group’s solution to the lab problem.	58	74	82	78
3. Our group worked efficiently.	52	57	56	58
4. I felt the other members of my group were contributing to the solution of the lab problem.	65	89	75	77
5. Our group did most tasks together.	65	72	68	71
6. Our group communicated well with each other, so each member understood what the heck was going on.	69	64	66	63

*Percentage of students answering Quite Often and Almost Always

two sets: “activity” group functioning, and “discussion” group functioning. Because eight tests were performed, the level of significance for each test is $\alpha = 0.05/8 = 0.00625$. The responses to the six “activity” group functioning questions are found in Table 4.15.

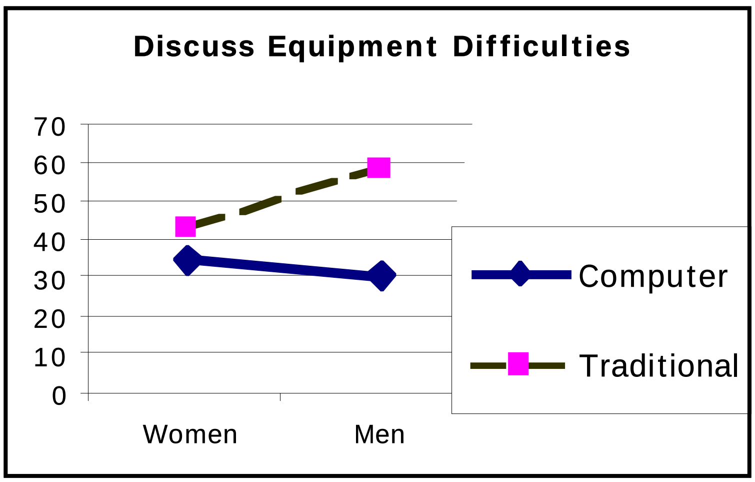
There were no significant differences between the women in the two treatments in their perceived group functioning (χ^2 (5)=7.99, p=0.16). The two groups of men did not differ in how they answered the group functioning questions (χ^2 (5)=1.74, p=0.88). There were no significant differences between

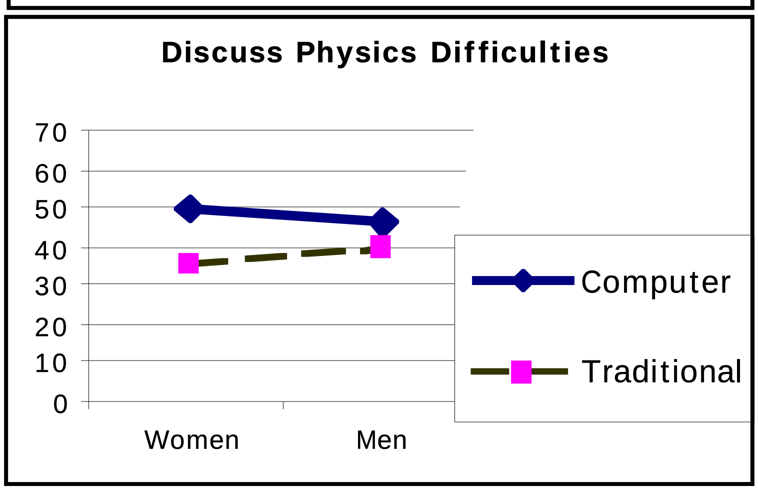
Table 4.16

Responses to "Discussion" Group Functioning Questions by Gender and Treatment

	Women in Computer Treatment (N=48)	Women in Traditional Treatment (N=47)	Men in Computer Treatment (N=125)	Men in Traditional Treatment (N=120)
Our group discussed equipment difficulties.	35	43	31	58
Our group discussed misunderstandings about the physics.	50	36	47	40

Figure 4.1
"Discussion" Interactions





the women and men in the computer treatment (χ^2 (5)=3.17, p=0.67). There were no significant differences between the women and men in the traditional treatment (χ^2 (5)=3.95, p=0.56). Because there were no significant differences among the four tests, there is no significant gender-treatment interaction for perceived group functioning.

The responses to the two "discussion" group functioning questions are listed in Table 4.16. Figure 4.1 shows the interaction plots for the two questions, based on these data.

There were no significant differences between the women in the two treatments in their perceived group functioning (χ^2 (1)=2.6, p=0.11). The two groups of men did not differ significantly in how they answered the group functioning questions (χ^2 (1)=6.4, p=0.011). There were no significant differences between the women and men in the computer treatment (χ^2 (1)=0.05, p=0.83). There were no significant differences between the women and men in the traditional treatment (χ^2 (1)=0.43, p=0.51). Looking at the interaction plots, it appears that the biggest contribution to the gender-treatment interaction is due to differences in the responses of men to the question of how often they discussed equipment difficulties in their groups.

Summary:

When gender-treatment interactions were looked for, the only place they appeared was in perceived group functioning. On the "activity" group functioning questions there was no difference, but on the "discussion" group functioning questions there was a difference. Attitudes and achievement did not indicate a gender-treatment interaction.

Summary

Achievement:

The MANCOVA test indicated significant differences in achievement for the two treatment groups. Students in the traditional treatment did better than students in the computer treatment on the FCI post-test.

Attitudes:

The two treatment groups of students felt the same way about the three components of the course: lecture, discussion session, and lab. Their attitudes towards the laboratory tools were the same.

Group Behavior:

Groups of students in both treatments spent the same amount of time in the three main parts of the lab: exploration, measurement, and analysis. When solving the lab problems, groups talked about the same things no matter which laboratory tools they were using. Students from both treatments responded similarly to questions about their perceived group functioning for the six "activity" questions. For the two "discussion" questions, the students in the computer treatment discussed misunderstandings about the physics more often, and they discussed equipment difficulties less often than did the students in the traditional treatment.

Gender: When examining possible interactions due to gender, only one of the three main questions ended up with an interaction. The perceived group functioning for discussing equipment and physics difficulties was different for the men and women in the two treatments. The group functioning for the activity questions indicated no interaction. In terms of attitudes and achievement, there were no gender-treatment interactions.

Chapter 5 Conclusions

The purpose of this study was to determine the effects of replacing traditional data collection and analysis tools with a computer data collection and analysis tool (VideoTool). Because the research literature on using computers in labs is ambiguous about the effects of using computers, this study was undertaken as part of the first phase of a two-phase implementation of the computers. If this first phase demonstrated that replacing the traditional tools with a computer tool had no adverse effects on the students, then the second phase of full implementation with new lab problems could begin.

For the two treatments (computer and traditional data collection and analysis tools, four different effects on students were examined: achievement, attitude, group behavior, and gender-treatment interactions. To measure achievement, two conceptual tests and overall course grades were used. Fifteen survey questions measured students' attitude towards the course and the laboratory tools. Observations of groups solving the lab problem and nine survey questions provided a picture of group behaviors. Gender data was collected for each measure so that possible gender interactions could be studied as well.

There were few differences found between the experimental computer treatment and the control traditional treatment.

Achievement

The first research question of this study was:

1. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change students' achievement?
   a. Do students in problem-solving laboratories with VideoTool (experimental treatment) gain equally well as students in problem-solving laboratories with traditional tools (control treatment) on a test of understanding kinematics?
   b. Do students in the two treatments gain equally on a test of understanding force?
   c. Do students in the two treatments do equally well on overall course grades?

The research literature on the use of computers in classrooms indicates mixed results. When implemented in a well-planned fashion, computers may have positive effects on achievement (Thornton, 1990; Linn, Layman, & Nachmias, 1987), or they may have no effect at all (Cordes, 1990; Leonard, 1992). This study was not about a full-scale implementation, but rather a simple replacement of traditional data collection and analysis tools with a computer tool. Achievement results were examined to verify that the replacement of tools did not harm the students' level of achievement.

For achievement, the MANCOVA indicated that there was a statistically significant overall difference between the two treatments. A closer inspection of the data indicated that the only significant difference was on the FCI post-test. This difference, however, was not educationally significant. Three ways of examining the effect size all suggested that the effect was very small. First, the difference only accounted for 2% of the variance ($\eta^2 = 0.02$). Second, the effect size (Cohen, 1969) was not large (ES=0.25). Third, the percentage difference between the adjusted means was 1.4 questions, or 5% of the test.

Replacing the traditional data collection and analysis tools with VideoTool did not affect students' overall grades or post-test scores on the TUG-K, and had a very small effect on students' post-test scores on the FCI. The replacement produced no meaningful differences.

<u>Attitude</u>

The second research question was:

2. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change students' attitudes?
    a. Do students in problem-solving laboratories with VideoTool (experimental treatment) have the same overall attitude towards the course as students in problem-solving laboratories with traditional tools (control treatment)?

b. Do students in the two treatments have the same attitude towards using the specific computer or non-computer tools used in the laboratory?

Computers are a part of modern life, and students use computers in many different daily situations. Most students enter their science and engineering courses expecting to see computers in the laboratory. By replacing traditional lab tools with a computer tool, students' attitudes towards the course overall and towards the lab tools used may be affected (Berger, Lu, Belzer, & Voss, 1994; Brasell, 1987). Attitudes were examined to determine if a new computer tool affected how students felt about the course and the data collection and analysis tools.

There were no differences in student attitudes about the course and computer tools between the two treatments. Responses to nine attitude questions about the three components of the course showed no significant differences between the two treatment groups. This leads to the conclusion that using a computer tool for data collection and analysis, instead of traditional tools, does not change students' attitudes about the course in general.

When examining attitudes towards the particular data collection and analysis tools used in the laboratory, there was no significant ($p<0.0125$) difference between the treatment groups. However, the significance was 0.04, which warranted a further look at the data. Most of the difference between the groups came from differing responses to the last question. Students in the computer treatment were slightly more likely to agree with the statement "I am looking forward to using VideoTool in my next physics class." Students in the traditional treatment were less likely to agree with the corresponding statement about using spark tape.

There are several possible reasons for this tendency of the treatment groups to answer differently. The first reason is simply that the students in the computer treatment did like using VideoTool better than students in the traditional treatment liked using spark tape and Polaroid film. A corollary to this is that the students in the traditional treatment strongly disliked using the spark tape. The second reason is that of a Hawthorne effect: students in the computer treatment were aware that they were in a different type of lab, and this raised attitudes slightly, simply because they felt they were receiving special treatment. Students in different lab sections talked together, and sometimes they wrote lab reports together. It is very reasonable to assume that students in the two types of labs (computer and traditional) were aware of the other type of lab.

Replacing traditional data collection and analysis tools with a computer tool did not change students' overall attitude toward the course or to the laboratory tools they were using.

Group Behavior

The third research question was:

3. In introductory physics courses with problem-solving laboratories, does replacing traditional data collection and analysis tools with VideoTool change how groups solve the laboratory problem?

a. Do groups in problem-solving laboratories with VideoTool (experimental treatment) spend the same amount of time in each part of the laboratory as groups in problem-solving laboratories with traditional tools (control treatment)?
b. Do groups in the two treatments talk about the same things while solving the laboratory problems?
c. Do students in the two treatments perceive their group functioning differently?

Because this course used a Cooperative Group Problem Solving pedagogy, there were concerns that using the computers would negatively affect group functioning in the labs (Jehng, 1997; Tao & Gunstone, 1997). Observations of student groups solving the lab problems demonstrated that this was not the case. There were no significant differences between the two treatments on the observation measures of what was done while solving the lab problem. Groups in both treatments spent the same amount of time in each part of the lab, and they talked about the same things while solving the lab problems. The replacement of traditional tools with VideoTool had no negative affects on the way that the groups solved lab problems. However, it is possible that changing the laboratory tools affected behaviors that were too complex for an outside observer to detect. Therefore, this study also examined students' perceived group functioning.

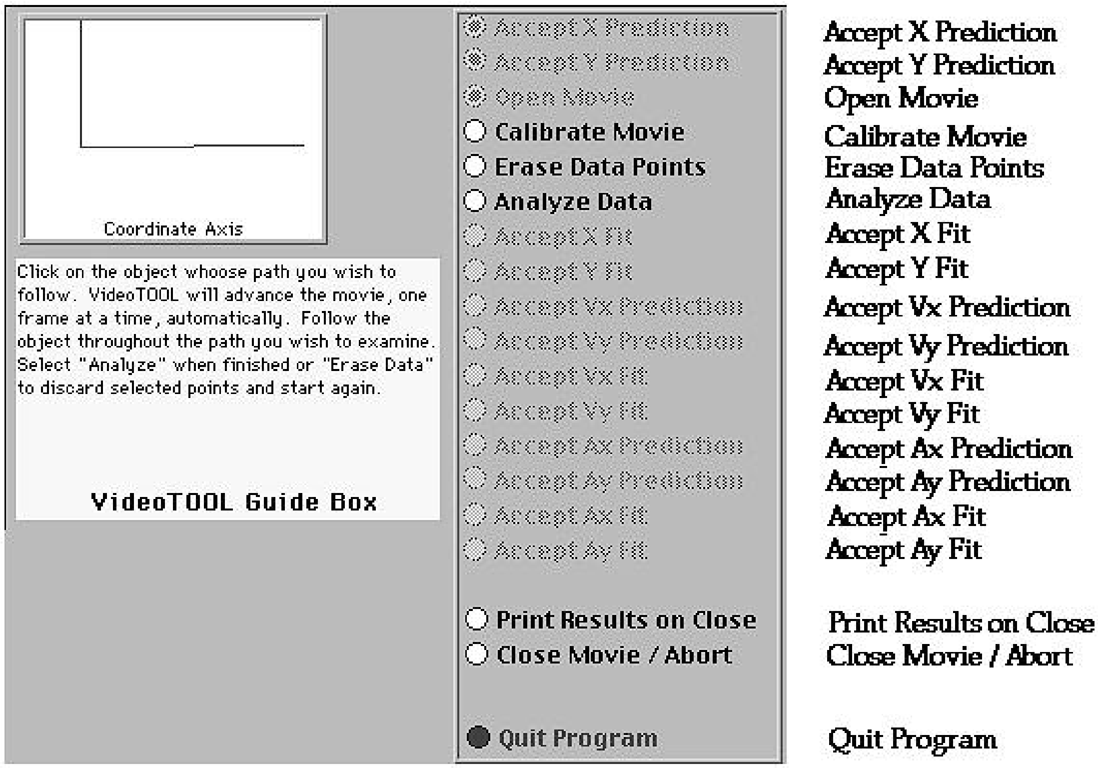
Two different aspects of group functioning were examined through responses to survey questions: "activity" (e.g. One person in our group did most of the data analysis.) and “discussion” (e.g. Our group discussed equipment difficulties.). There were no significant differences in how students in the two treatments perceived their group’s “activity.” There was a significant difference in how students in the two treatments perceived their group’s “discussion.” Students in the computer treatment answered that their groups discussed equipment difficulties less often and physics misunderstandings more often than students in the traditional treatment.

The traditional treatment laboratories had more equipment, and older equipment, than the computer treatment laboratories. The different responses to the discussing equipment difficulties question could have arisen from this fact.

One of the concerns raised about replacing traditional data collection and analysis tools with VideoTool was that students might focus on the computer itself instead of the physics. Students did not perceive that this was happening in the laboratories. Yet observations of groups solving the lab problems did not match the students’ perceptions. One explanation for this mismatch involves the design of the computer tool. VideoTool used specific physics language in its menu. When students in the computer treatment were analyzing their data, they were using physics language, because using VideoTool required discussing the physics of the analysis. Figure 5.1 shows the VideoTool menu including the position, velocity, and acceleration predictions and fits. VideoTool also forced students to discuss and complete one step of the analysis before they could move on to the next step. Students could not skip steps during the analysis.

Figure 5.1

VideoTool Menu



The coding scheme for the observations of groups solving the lab problems also contributed to this mismatch. Two codes of particular interest are “talking physics” and “talking about analysis.” The way the observers coded interactions meant that if groups were discussing the analysis, and saying “The next step is to determine what our velocity was,” the observer would code this as talking about analysis, not talking physics. Statements such as this could have led to students perceiving that they were discussing physics more often, even though the observations would show no difference in talking physics.

Table 5.1

Talking Physics and Talking about Analysis by Treatment

	Computer treatment (N=45 groups)	Traditional treatment (N=34 groups)
1. Talking physics	5.7	6.4*
4. Analysis	31.9	22.8

* Percentage of total time spent solving the lab problems

This hypothesis is supported by the observation data. As seen in Table 5.1, groups in the computer treatment spent more time (32%) discussing the analysis of the problem than groups in the traditional treatment (23%). If this were true, this accounts for the difference between students' perceptions and the observations made.

In summary, replacing the traditional laboratory tools with a computer tool did not adversely affect observed group behaviors while solving the lab problems. Groups did not differ in time spent on each part of the lab, or in what they were talking about overall. Students' perceptions of the time their group spent discussing equipment and physics difficulties was different, but this difference may be explained by an interaction between the design of VideoTool and the observation coding scheme.

Gender

The fourth research question was:

4. Are there any gender-treatment interactions?

   a. Is there a gender-treatment interaction for the three measures of achievement?
   b. Is there a gender-treatment interaction for students' attitudes towards the overall course and towards the particular laboratory tools?
   c. Is there a gender-treatment interaction for how students perceive their group functioning?

The research literature shows that women and men respond to computers differently (Cheek & Agrusso, 1995; Shasaani, 1997). Gender-treatment interactions were examined to determine if the replacement of traditional tools with VideoTool would affect one gender more than the other. Interactions were looked for in achievement, attitude, and perceived group behaviors.

There was no significant interaction between gender and treatment for achievement. Students' attitudes towards the three components of the course and the laboratory tools did not show a significant interaction. There was no significant interaction on perceived group "activity" behaviors. Only perceived group behaviors about "discussing" showed a significant interaction. The men in the traditional treatment spent more time discussing equipment difficulties. A hypothesis for this difference comes from two sources. First, the traditional treatment laboratories had more equipment and older equipment than the computer treatment laboratories did. Second, the research literature indicates that men interact more with laboratory equipment than women do (Kahle, 1990).

Men tend to dominate the hands-on parts of labs. Combining these facts suggests that men in the traditional treatment were working more with equipment, and therefor perhaps feeling that they had spent more time discussing equipment difficulties. However, this difference is small when included with all the other data.

Replacing the traditional data collection and analysis tools with VideoTool did not affect the ways women and men compared on achievement, attitudes, and perceived group behaviors.

Educational Implications

The biggest concern that the Physics Education Research and Development Group had with replacing the traditional laboratory tools with a computer tool was that something valuable would be lost because of the replacement. Addressing this concern was the main thrust of this study—phase one of the implementation procedure. By examining achievement, attitudes, and group behaviors, it appears that nothing was negatively impacted by simply replacing laboratory tools with a computer tool. With these results, the Physics Education Research and Development Group can move on to phase two: rewriting laboratory problems and adjusting the computer tool to maximize student learning. The results also indicate that the computer tool used during the pilot-testing was well designed. Students who used VideoTool were spending time in analysis which they perceived to be spent talking about physics. The tool was a good fit to the pedagogy of the lab, and allowed groups to solve the lab problem and focus on the physics.

Research Implications

This study was concerned with a unique situation: an introductory physics course for scientists and engineers which uses a rare pedagogy based on cognitive apprenticeship. Computer use in this type of course has not been widely studied. This study expands what is known about adding computers to laboratories and this type of pedagogy.

The research literature suggests that computers can lead to increases in student achievement or no effect at all. In this study, use of the computer tool had no effect on two measures of achievement, and a very small effect on a third. Because of the integrated nature of the course, this study looked at both an overall measure of achievement and two more focused measures, and found similar results for the three.

In terms of how computers affect attitudes, this study specifically asked students about their attitudes towards the course overall and the tools they used in the laboratory. Little research has been done on how computers affect attitudes; most of the mentions in the research literature are simply the feelings of the researcher with little evidence to back them up. In this situation, where the computer was only a tool replacing other laboratory tools, the computer had little effect on students' attitudes towards the course or the laboratory tools used. The only slight difference was in the response to a statement asking the students if they were looking forward to using spark tape or VideoTool in their next physics class.

This study also contributes to the literature on computers in classrooms by examining several different aspects of student interaction with a course: not only achievement but also attitudes and group behaviors. Few research studies have looked at more than one of these topics. The issue of gender was also examined, but only one interaction was found; in perceived group behaviors about discussion.

Future Research

This study raised two interesting questions. First, there was a mismatch between students' perception of time spent discussing physics and the observation data for talking physics. This mismatch can be explained by looking at the interaction codes and the design of VideoTool. But a deeper look into these data would be interesting. When discussing the analysis of the lab data, are students using physics language without discussing the deeper physics meanings? Or are they taking their cue from the language in VideoTool, and really discussing the physics behind the problems, as one would hope?

A second question also concerns the actions of the students. The observations were not designed to examine the particular actions of the groups in great detail. Several researchers have suggested that the computer can lead to faster, more accurate data taking, and computers can allow for taking multiple sets of data in one lab session (Ager, 1990; Thornton, 1990; Nordling, 1990). A more detailed observation of the behavior of the groups could answer more questions, such as what the groups were doing when in the measurement phase of the lab. Were groups in the computer treatment taking more data, retaking data, or using the computer in other ways to get data more quickly than the groups in the traditional treatment?

The third question arises from the achievement data. When examining the differences in achievement, neither the gender or the treatment main effect, nor the gender-treatment interaction accounted for much of the variation in achievement scores. Pretest scores are taken into account already as covariates. There is a difference in achievement between the treatments, but where does this difference come from? What other factors are affecting how well students do on conceptual tests and course grades?

Summary

This study investigated the effects of replacing traditional data collection and analysis tools with a computer tool in a particular pedagogy. Because the research literature indicated mixed results, a cautious approach was taken. Replacing the traditional laboratory tools with a computer tool had little effect on students. These results are encouraging and allow the next stage of implementation to begin. With the next stage comes more research, but that, dear reader, is a project for another researcher.

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Appendix A

Demographic Questionnaire

Student Background Information

Please take a moment to complete this questionnaire. The information you provide will help the Physics Department evaluate the usefulness of the laboratory. Your name will be used to match this evaluation with the other questionnaires you have completed this quarter. Your answers and comments will be kept confidential. Completing this questionnaire is voluntary and will not affect your grade in this or any other course. Your cooperation is appreciated.

INSTRUCTIONS FOR COMPLETING THIS QUESTIONNAIRE

- Use a number 2 or H / HB pencil to fill out the answer sheet.
- Fill in the bubbles completely.
- Erase completely any marks you made by mistake.
- See marking instructions on side 2 of the answer sheet if you have other questions.

- Please fill in your:
  ① Name
  ② Identification Number
  ③ Course (i.e. 1251) in blanks G - J
  ④ Laboratory Section (i.e. if you're in 1251.3 lab section 21, enter 21) in blanks L-M
  ⑤ Sex, Grades, Status, and Class

OVERVIEW FOR THIS QUESTIONNAIRE

If you were given a separate test booklet {such as the Force Concept Inventory (FCI), or the Force Motion Conceptual Evaluation (FMCE) or the Test for Understanding Graphs (TUG)}, do this test first in spaces 1 through 72. You will not use all these question spaces. When you have finished the test, proceed to question 73.

If you were **not** given a separate test booklet, start with question 75.

As always, if you have any questions, please feel free to ask your TA.

PHYSICS DIAGNOSTIC TESTS:

If you were not given a separate test booklet, start with question 75.
If you were given a separate test booklet, start with question 1 of that test booklet. Complete the test questions in spaces 1-72. You will not use all these spaces. Then start with question 73 on the back of the answer sheet.

Diagnostic tests opinions

When you have finished the test, turn the answer sheet over and answer the following questions:

73. How confident are you that your answers are correct?
    - a Just guessing at answers.
    - b Not at all confident.
    - c Somewhat confident.
    - d Confident.
    - e Very confident.
74. Do you think this test was an accurate measure of the physics you know?
    - a No.
    - b No opinion.
    - c Yes.

YOUR BACKGROUND:

Your major. If you are <u>undecided</u>, choose 77j. If you are a double major, select your primary major.

75. Engineering
    - a Aerospace Engineering
    - b Agricultural Engineering
    - c Civil Engineering
    - d Chemical Engineering
    - e Electrical Engineering
    - f Geological Engineering
    - g Industrial Engineering
    - h Mechanical Engineering
    - i Engineering -- Undecided
76. Physical Sciences
    - a Astronomy / astrophysics
    - b Chemistry
    - c Geology / geophysics
    - d Material Science
    - e Physics
    - f Biological Sciences
    - g Computer Science
    - h Mathematics / Statistics
    - i Social Science
    - j Science - Undecided
77. Other
    - a Business, Management, and Accounting
    - b Education
    - c Humanities
    - d Pre-med / Pre-vet
    - e Pre-law
    - f Health / Medical
    - g Physical Therapy
    - h Agriculture / Ecology
    - i Architecture / Landscape architecture
    - j Undecided

Your physics and math background

78. How well **prepared** do you feel to deal with the subject matter of physics?
    - a Totally unprepared.
    - b Unprepared.
    - c Somewhat prepared.
    - d Prepared.
    - e Very well prepared.
79. Have you taken a physics course before? (select only one)
    - a No.
    - b Yes, in high school only.
    - c Yes, in college only.
    - d Yes, both in college and in high school.
80. Are you repeating this course?
    - a No.
    - b Yes. I took this course before at the University of Minnesota.
    - c Yes. I took a similar course at another college or university.
81. What was the last high school math class you completed?
    - a Algebra.
    - b Geometry.
    - c Trigonometry.
    - d Pre-calculus, Functions, or Analysis.
    - e Calculus.
    - f Other, more advanced math in high school.
82. What was the last college math class you completed **prior** to this course?
    - a I have not taken a college math class.
    - b Algebra.
    - c Geometry.
    - d Trigonometry.
    - e Pre-calculus, Functions, or Analysis.
    - f First-quarter calculus.
    - g Second-quarter calculus.
    - h Third-quarter calculus.
    - i Multivariable calculus.
    - j Other, more advanced math.
83. When did you take your most recently completed math course?
    - a Last term.
    - b Two terms ago.
    - c This year.
    - d Last year.
    - e 2-3 years ago.
    - f 4-5 years ago.
    - g More than five years ago.
84. Are you enrolled in a math course this quarter?
    - a No.
    - b Yes.
85. How many quarters of science, other than this course, have you taken in college?
    - a This is my first college science course.
    - b I'm taking another first, college science course concurrently with this class.
    - c 1.
    - d 2.
    - e 3.
    - f 4.
    - g 5.
    - h 6 or more.

86. How computer literate do you consider yourself?
   - a Uncomfortable with computers.
   - b Marginally computer literate.
   - c Fairly computer literate.
   - d Very computer literate.
   - e Extremely computer literate.

Your academic workload background

87. What is your approximate college GPA on a 4.0 system?
   - a I do not have a GPA at the University of Minnesota.
   - b 3.4-4.0
   - c 2.8-3.3
   - d 1.8-2.7
   - e 1.0-1.7
   - f Below 1.0
88. What grade do you expect to receive in this course?
   - a A
   - b B
   - c C
   - d D
   - e F
89. Approximately how much time per week do you anticipate spending on this course in addition to regular class sessions?
   - a Less than two hours per week.
   - b 2-5 hours per week.
   - c 6-10 hours per week.
   - d 10-15 hours per week.
   - e More than 15 hours per week.
90. How many total course credits are you taking this quarter?
   - a 0-4
   - b 5-8
   - c 9-12
   - d 13-16
   - e More than 16.
91. How many hours per week are you employed?
   - a None.
   - b 1-10 hours per week.
   - c 11-20 hours per week.
   - d 21-30 hours per week.
   - e More than 31 hours per week.
92. What is your age?
   - a 17 or younger
   - b 18-19
   - c 20-21
   - d 22-23
   - e 24 or older
93. What type of residence do you live in?
   - a Dormitory on-campus
   - b Fraternity / sorority
   - c Living near campus
   - d Living off-campus
   - e University family housing
   - f With parents / family
   - g Other

Your Beliefs:

For the following fifteen statements (94-108), choose the code that best describes your opinion. Use the following codes to answer these questions.

1 = Strongly Disagree 2 = Disagree 3 = Neutral 4 = Agree 5= Strongly Agree

Answer the questions by selecting the code that best expresses your feelings. Work quickly. Don't over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple. If you do not understand a statement, leave it blank. If you understand, but have no strong opinion one way or other, circle 3. If an item combines two statements and you disagree with ***either one****, choose 1 or 2.*

94. "Problem-solving" in physics basically means matching problems with facts or equations and then substituting values to get a number.
95. No matter how hard I try, some people just don't like me.
96. Physical laws have little relation to what I experience in the real world.
97. Only a few specially qualified people are capable of really understanding physics.
98. For the most part, the grade I receive in this course will be influenced by accidental happenings.
99. To understand physics, I think about my personal experiences and relate them to the topic being analyzed.
100. The most crucial thing in solving a physics problem is finding the right equation to use.
101. There is rarely such a thing as an unfair test if I am well prepared.
102. Physics is related to the real world and it sometimes helps to think about the connections, but it is rarely essential for what I have to do in this course.
103. Learning physics helps me to understand situations in my everyday life.
104. There is a direct connection between how hard I study and the grades I get.
105. When I solve most exam or homework problems, I explicitly think about the concepts that underlie the problems.
106. "Understanding" physics basically means being able to recall something you've read or been shown.
107. To be able to use an equation in a problem (particularly a problem that I haven't seen before), I need to know more than what each term in the equation represents.
108. Many times exam questions tend to be so unrelated to course work that studying is really useless.

Appendix D

Final Course Evaluation—Complete Version

Course Evaluation for the Physics Department

Please take a moment to complete this questionnaire. The information you provide will help the Physics Department evaluate the various components of the course. Your name will be used to match this evaluation with the other questionnaires you have completed this quarter. Your answers and comments will be kept confidential. Completing this questionnaire is voluntary and will not affect your grade in this or any other course. Your cooperation is appreciated.

INSTRUCTIONS FOR COMPLETING THE ANSWER SHEET

- Use a #2 or H / HB pencil to fill out the answer sheet.
- Fill in the bubbles completely.
- Erase completely any marks you made by mistake.
- See marking instructions on side 2 of the answer sheet if you have other questions.

- Please Fill in your:
  ① Name
  ② Identification Number
  ③ Course (i.e., 1251) in blanks G - J
  ④ Laboratory Section (i.e., if you are in 1251.3 lab section 21, enter 21) in blanks L - M.
  ⑤ Sex, Grades, Status, and Class

OVERVIEW FOR THIS QUESTIONNAIRE

- Do the Physics Diagnostic Test (Force Concept Inventory or Test for Understanding Graphing -- Kinematics) first in spaces 1 through 49. *You will not use all of these spaces.*

- When you have finished the test, go to **space 50** on the answer sheet and answer the following questions in each section:

SECTION I: YOUR BELIEFS:

For the following fifteen statements (50-64), choose the code that best describes your opinion. Use the following codes to answer these questions.

A = Strongly Disagree B = Disagree C = Neutral D = Agree E= Strongly Agree

*Answer the questions by selecting the code that best expresses your feelings. Work quickly. Don't over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple. If you do not understand a statement, leave it blank. If you understand, but have no strong opinion one way or other, mark C. If an item combines two statements and you disagree with **either one**, choose A or B.*

50. "Problem-solving" in physics basically means matching problems with facts or equations and then substituting values to get a number.
51. No matter how hard I try, some people just don’t like me.

52. Physical laws have little relation to what I experience in the real world.
53. Only a few specially qualified people are capable of really understanding physics.
54. For the most part, the grade I receive in this course will be influenced by accidental happenings.
55. To understand physics, I think about my personal experiences and relate them to the topic being analyzed.
56. The most crucial thing in solving a physics problem is finding the right equation to use.
57. There is rarely such a thing as an unfair test if I am well prepared.
58. Physics is related to the real world and it sometimes helps to think about the connections, but it is rarely essential for what I have to do in this course.
59. Learning physics helps me to understand situations in my everyday life.
60. There is a direct connection between how hard I study and the grades I get.
61. When I solve most exam or homework problems, I explicitly think about the concepts that underlie the problems.
62. "Understanding" physics basically means being able to recall something you've read or been shown.
63. To be able to use an equation in a problem (particularly a problem that I haven't seen before), I need to know more than what each term in the equation represents.
64. Many times exam questions tend to be so unrelated to course work that studying is really useless.

SECTION II: LECTURE:

Please rate the extent you agree or disagree with each statement about the lectures by marking the appropriate letter on your answer sheet.

A = Strongly Disagree B = Disagree C = Neutral D = Agree E= Strongly Agree

65. The lectures were a waste of time.
66. The lectures helped to clarify ideas from the text.
67. The instructor covered too little material in the course.
68. The main points of the lecture were clearly stated and emphasized.
69. More lecture time should be spent illustrating good problem solutions.
70. The lectures required my active intellectual involvement.

SECTION III: DISCUSSION SECTION

Please rate the extent you agree or disagree with each statement about the discussion sections by marking the appropriate letter on your answer sheet.

A = Strongly Disagree B = Disagree C = Neutral D = Agree E = Strongly Agree

71. Solving problems with my group helped me to understand the course material.
72. The discussion sections were a waste of time.
73. When my group got together, we knew just what we were supposed to do.
74. My group worked well together on the assigned problems.
75. The discussion problems provided useful guidance for solving problems on the individual exams.
76. My TA gave us useful help when we were stuck.

SECTION IV: LABORATORY SECTION

Please rate the extent you agree or disagree with each general statement about the laboratory sessions by marking the appropriate letter on your answer sheet.

A = Strongly Disagree B = Disagree C = Neutral D = Agree E = Strongly Agree

77. The laboratory problems provided useful guidance for solving problems on the individual exams.
78. The laboratory problems helped me to understand the concepts covered in class.
79. The laboratory sessions were a waste of time.
80. The written instructions for the laboratory problems were clear enough for our group to solve the problems.
81. My TA gave us useful help when we were stuck.
82. Overall, the laboratory problems were interesting.

*Please indicate **how often** the following events occurred during laboratory sessions by marking the appropriate letter on your answer sheet.*

A= Hardly ever B= Not very often C= Sometimes D= Quite often E= Almost always

83. Our group discussed equipment difficulties.
84. Our group discussed misunderstandings about the physics.
85. One person in our group did most of the data analysis.
86. I felt I was contributing to our group's solution to the lab problem.
87. Our group worked efficiently.
88. I felt the other members of my group were contributing to the solution of the lab problem.
89. Our group did most tasks together.
90. Our group divided most of the tasks.
91. Our group communicated well with each other, so each member understood what the heck was going on.

Computer treatment Section Version:

Please rate the extent you agree or disagree with each statement about using **VideoTool** in the labs by marking the appropriate letter on your answer sheet.

A = Strongly Disagree B = Disagree C = Neutral D = Agree E = Strongly Agree

92. I consider myself computer literate.
93. Although it took time to learn VideoTool, it was time well spent.
94. I felt that comparing our prediction equation to our collected data helped me understand the relationship between our graphs and the observed motion.
95. VideoTool taught me the importance of selecting an appropriate origin and / or axis and meaningful units in solving problems.
96. Using VideoTool helped me understand the equations I used in class.
97. Using VideoTool helped my understanding of derivatives.
98. I found the printed graphs and equations useful in writing my lab reports.
99. I was careful to select the same place on the moving object each time I selected a data point.
100. If necessary, I would enter unrealistic values into my fit equations to get the line through most of my points.
101. The position fit helped me to predict my velocity and acceleration fits.
102. The instructions given in the VideoTool Guidebox were generally helpful.
103. I am looking forward to using VideoTool in my next physics course.

Traditional treatment Section Version:

92. I consider myself computer literate.
93. Although it took time to learn to use spark tape, it was time well spent.
94. I felt that comparing our prediction equation to our collected data helped me understand the relationship between our graphs and the observed motion.
95. Analyzing spark tape data and Polaroid film taught me the importance of selecting an appropriate origin and / or axis and meaningful units in solving problems.
96. Analyzing spark tape data helped me understand the equations I used in class.
97. Analyzing spark tape data helped my understanding of derivatives.
98. I found doing data analysis in lab with my group useful in writing my lab reports.
99. I was careful to measure accurately the distance each time I selected another data point.
100. If I got unrealistic values from my data analysis, I would move on so I could finish the problem.
101. The instructions in the Appendix for analyzing spark tape data were generally helpful.
102. I am looking forward to using spark tapes / Polaroid film in my next physics course.

Computer treatment Section Version:

Please indicate ***how often*** *the following events occurred during laboratory sessions by marking the appropriate letter on your answer sheet.*

A = Almost never B = Not very often C = Sometimes D = Quite often E = Almost always

104. I used the computer for my group.
105. We used the lab manual while working in the lab room.
106. We would play the movie to observe the motion before we started to take data.
107. We needed to retake a movie after we had started using VideoTool.
108. There were significant differences between our predicted graphs and our data.
109. We did not have the necessary equation in VideoTool.
110. We estimated the uncertainties in our measurements.
111. We rushed through VideoTool because we ran out of time.
112. We guessed (or ignored) the coefficients for the prediction equation we entered in VideoTool.
113. We used the "Rotate" feature to change the axis in VideoTool.
114. We aborted or exited VideoTool and started again.

Traditional treatment Section Version:

103. I used the apparatus to take data for my group.
104. We used the lab manual while working in the lab room.
105. We observed the motion before we started to take data.
106. We needed to retake our data after we had already started to analyze it.
107. There were significant differences between our predicted graphs and our data.
108. We estimated the uncertainties in our measurements.
109. We rushed through the lab problem because we ran out of time.

SECTION V: OVERALL EVALUATION

115. Mark the **one** statement below which best describes your typical use of the *Solutions Manual*.
    A. I did not usually read or use the solutions manual.
    B. I usually used it to get started doing a problem.
    C. I usually used it to get help when stuck doing a problem.
    D. I usually used it to check my method or answer after doing the problem.
    E. I usually studied the solutions in the manual instead of trying to solve the homework problems.

116. Mark the **one** statement below which best describes your use of the *Competent Problem Solver* booklet.
    A. I did not read or use the booklet .
    B. I used it infrequently.
    C. I used it mostly at the beginning of the course.
    D. I used it mostly at the end of the course.
    E. I used it fairly consistently throughout the course.

Rank order the following components of the course from the ***most*** *useful (1) to the* ***least*** *useful (8) in helping you learn physics. Mark your rank next to each course component on the answer sheet. Only use each number (1 - 8) once.*

117. Homework
118. Laboratory
119. Lectures
120. Lecturer Office Hours
121. Quizzes and Exams
122. Discussion Sessions (Recitation)
123. TA Office Hours
124. Textbook

125. Mark the **one** statement below which best describes the course structure you think would help you learn physics the best.
    A. I would learn physics better if one lecture were eliminated (i.e., only two lectures a week), and there were two discussion (recitation) sessions each week.
    B. I would learn physics better if one lecture were eliminated (i.e., only two lectures a week), and the lab time was increased from two to three hours each week.
    C. I would learn physics better if the lab were eliminated and there were two more lectures each week.
    D. I would learn physics better if the discussion (recitation) session were eliminated and there was one more lecture each week.
    E. I learn best with the present structure of three lectures, one discussion (recitation), and one two-hour lab each week.

SECTION II: OVERALL ATTENDANCE

126. The percentage of time I attended lecture was about:
   - A. 0 - 20%
   - B. 20 - 40 %
   - C. 40 - 60%
   - D. 60 - 80%
   - E. over 80%

127. How often did you go to your professor's office hours for help:
   - A. I never went.
   - B. 1 - 2 times
   - C. 3 - 4 times
   - D. 5 - 6 times
   - E. 7 - 9 times
   - F. more than 9 times

128. How many laboratory sessions did you **miss** this quarter:
   - A. None
   - B. 1 sessions
   - C. 2 sessions
   - D. 3 sessions
   - E. 4 sessions
   - F. more than 4 sessions

129. How many discussion sessions did you **miss** this quarter:
   - A. None
   - B. 1 sessions
   - C. 2 sessions
   - D. 3 sessions
   - E. 4 sessions
   - F. more than 4 sessions

130. How often did you go to the TA's office hours (in room 140) for help?
   - A. I never went.
   - B. 1 - 2 times
   - C. 3 - 4 times
   - D. 5 - 6 times
   - E. 7 - 9 times
   - F. more than 9 times

131. The percentage of the assigned textbook reading I did was about:
   - A. 0 - 20%
   - B. 20 - 40 %
   - C. 40 - 60%
   - D. 60 - 80%
   - E. over 80%

132. The percentage of the assigned homework problems I did was:
   - A. 0 - 20%
   - B. 20 - 40 %
   - C. 40 - 60%
   - D. 60 - 80%
   - E. over 80%

Appendix E

Sample Laboratory Problems
Spark Tape Version and VideoTool Version

LAB I: PROBLEM #2: MOTION DOWN AN INCLINE
(SPARK TAPE VERSION)

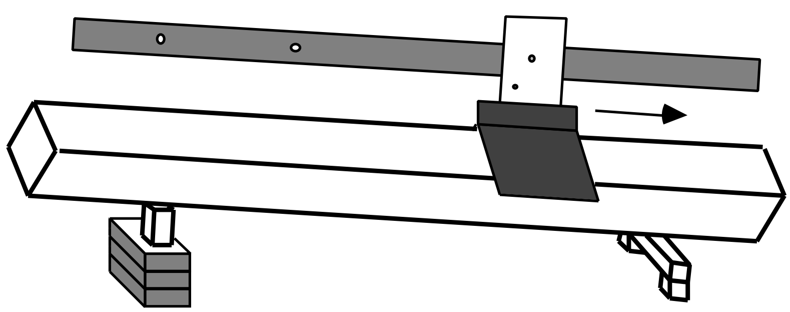
You are trying design the best set of skis for cross-country skiing. First you need to know the ideal motion of a skier gliding down a hill. You know that the skier's velocity increases as she glides down the hill. Does the skier's acceleration also increases as she glides down the hill? To resolve the issue, you decide to measure the acceleration of a glider going down an inclined air track.

> How does an object accelerate as it moves down a nearly frictionless ramp?

In Problem #1 the velocity of the glider was constant, so the instantaneous velocity of the glider was equal to its average velocity. When the velocity is not constant (as in this problem) this is not true. It is straightforward to determine the average velocity of an accelerating object from position and time measurements, but determining instantaneous velocities is much more difficult. For this problem you will use two different, yet related, techniques to calculate instantaneous velocities and accelerations from your spark tapes.

EQUIPMENT

The equipment, air track and glider, is the same as for Problem #1.



The air track is tilted at an angle and the glider is released from rest near the top of the track.

PREDICTION

Make a rough sketch of the expected the acceleration-versus-time graph for a glider released from rest near the top of an inclined track. How does that compare to a glider which has a constant, non-zero, acceleration, an acceleration which is constantly increasing.

Do you think the glider's acceleration ***changes*** *as it moves down the track? If so, how does the acceleration change (increase or decrease)? Does the acceleration change uniformly, more near the top of the track, or more near the bottom of the track? Or do you think the acceleration is constant (does not change) as the glider moves down the track? Make you best guess and explain your reasoning.*

METHOD QUESTIONS

The following questions may help with your prediction and the analysis of your data.

1. How would the *spark pattern* on the wax tape look if the glider moved down the track with precisely a constant acceleration? With an increasing acceleration? With a decreasing acceleration? Make rough sketches and explain your reasoning. Which of these patterns do you expect to observe in this problem? Why?

2. How would you expect a *position-versus-time graph* to look for a glider moving with a constant acceleration? With an increasing acceleration? With a decreasing acceleration? Make rough sketches and explain your reasoning. Which of these graphs do you expect to observe in this problem? Why?

3. How would you expect a *instantaneous velocity-versus-time graph* to look for a glider moving with a constant acceleration? With an increasing acceleration? With a decreasing acceleration? Make rough sketches and explain your reasoning. Which of these graphs do you expect to observe in this problem? Why?

4. How would you expect an *instantaneous acceleration-versus-time graph* to look for a glider moving with a constant acceleration? With an increasing acceleration? With a decreasing acceleration? Make rough sketches and explain your reasoning.

Now you can make your prediction for this problem. Which of these graphs do you expect to observe in this problem? Why?

EXPLORATION

Slant the air track at an angle by raising the end of the air track that is supported by one leg. If you raise the air track by the end which is supported by two legs, the air track might fall over.

Start the glider from rest near the top of the track. Observe the glider as it moves down the inclined track. Is it important to level the air track with the table before slanting it?

What is the best way to change the angle of the air track in a reproducible way? How are you going to measure this angle with respect to the level air track? *Hint: Think trigonometry!*

Try several different angles. If the angle is too large the glider may rub on the air track; if it is too small it will be difficult to measure an acceleration. Determine the useful range of angles for your air track. Refer back to the range of velocities you determined in problem #1.

DO NOT TOUCH ANYTHING METAL ON THE APPARATUS WHILE THE SPARK TIMER IS IN OPERATION! It operates at **10,000 volts** and can give you a nasty shock.

Remember to select a setting on the air supply which will allow you to investigate the motion properly. Think about possible undesirable effects arising from an air flow which is too high or too low.

MEASUREMENT

Choose one angle which will give you the clearest measurement of the difference between this motion and your result for constant velocity motion. Make a spark record of the glider moving down the track at that angle. *Don't forget to measure and record the angle (with estimated uncertainty).*

Does the spark record look like your first method question? If not, explain.

How much accuracy from your meter stick do you need to determine an acceleration with at least two significant figures?

Note: Be sure to record your measurements with the appropriate number of significant figures (see Appendix B) and with your estimated uncertainty (see Appendix C). Otherwise, the data are nearly meaningless.

ANALYSIS

In this problem you will analyze your spark tapes using two different techniques -- a graphical technique and a numerical technique. After you have completed both techniques, you should decide on the advantages and disadvantages of each.

1. **The Graphical Technique:** Create a data table of positions and times from your spark tape. Make a graph of position versus time from your data. How does it compare with your graph second method question? Calculate the slopes of several tangents to the curve, and use this data to draw an instantaneous velocity-versus-time graph. If you are unfamiliar with this procedure, see Appendix E . How does this instantaneous velocity-versus-time graph compare with your third method question? Finally, construct the instantaneous acceleration-versus-time graph from the instantaneous velocity-versus-time graph. How does this instantaneous acceleration-versus-time graph compare with your prediction?

2. **The Numerical Technique:** Use the definition of instantaneous velocity (the limit of the average velocity as $\Delta t \rightarrow 0$) to approximate instantaneous velocities at specific times, and add this column of data to your data table. If you are unsure how to do this, see Appendix E. Use the same kind of procedure to obtain a column of approximate instantaneous acceleration data. From your table, make graphs of position versus time, instantaneous velocity versus time and instantaneous acceleration versus time. How do these graphs compare to your predictions?

Now compare the two analysis techniques. What are the strengths of each technique? The weaknesses?

CONCLUSION

Were you right about how a skier accelerates down a nearly frictionless hill? If yes, state your result in the most general terms supported by your analysis. If no, describe what you convinced you. What are the limitations on the accuracy of your measurements and analysis?

LAB I: PROBLEM #2: MOTION DOWN AN INCLINE
(VIDEOTOOL VERSION)

You and your co-worker are trying to determine the acceleration of a car rolling down a hill without any brakes. You both agree that the car's velocity increases as it rolls down the hill. Your co-worker believes that the car's acceleration also increases as it rolls down the hill. Do you agree with your co-worker? To resolve the issue, you decide to measure the acceleration of a cart down an inclined track.

?

How does an object accelerate as it moves down a ramp?

EQUIPMENT

For this experiment you will use VideoTool, a stopwatch and a meter stick. You will also have a cart with four wheels to roll down an incline.

PREDICTION

Make a rough sketch of what *your co-worker* expects the acceleration-versus-time graph to look like for a cart released from rest near the top of an inclined track. Now make a rough sketch of what *you* expect the acceleration-versus-time graph to look like.

Do you think the cart's acceleration ***changes*** *as it moves down the track? If so, how does the acceleration change (increase or decrease)? Does the acceleration change uniformly, more near the top of the track, or more near the bottom of the track? Or do you think the acceleration is constant (does not change) as the cart moves down the track? Make your best guess and explain your reasoning.*

METHOD QUESTIONS

The following questions may help with your prediction and the analysis of your data.

1. How would you expect a *position-versus-time graph* to look for a cart moving with a constant acceleration? With an increasing acceleration? With a decreasing acceleration? Make rough sketches and explain your reasoning. Why?

2. How would you expect an *instantaneous velocity-versus-time graph* to look for a cart moving with a constant acceleration? With an increasing acceleration?

With a decreasing acceleration? Make rough sketches and explain your reasoning. Why?

3. How would you expect an *instantaneous acceleration-versus-time graph* to look for a cart moving with a constant acceleration? With an increasing acceleration? With a decreasing acceleration? Make rough sketches and explain your reasoning.

You should be able to complete the prediction for this problem.

EXPLORATION

What is the best way to change the angle of the incline in a reproducible way? How are you going to measure this angle with respect to the table? *Hint: Think trigonometry!*

Start the cart from rest near the top of the track. Observe the cart as it moves down the inclined track. Where is the best place to release the cart so it does not damage the equipment?

Where is the best place to put the camera? Is it important to have most of the motion in the center of the picture? Which part of the motion do you wish to capture?

What is the total distance through which the cart rolls? What is the best procedure for timing this motion? Create and record your measurement plan.

MEASUREMENT

Choose one angle which will give you the clearest measurement of the difference between this motion and your result for constant velocity motion. Make a video of the cart moving down the track at that angle. *Don't forget to measure and record the angle (with estimated uncertainty).*

How much accuracy from the meter stick and stopwatch is necessary to determine an acceleration with at least two significant figures?

Note: Be sure to record your measurements with the appropriate number of significant figures (see Appendix B) and with your estimated uncertainty (see Appendix C). Otherwise, the data are nearly meaningless.

ANALYSIS

Look at the graphs you produced with VideoTool. How do they compare to your predictions?

Calculate the acceleration of the cart from your stopwatch and meter stick measurements.

Compare the accelerations for the cart you found with VideoTool to your acceleration measurement using a stopwatch. How do they compare?

CONCLUSION

Was your friend right about how a cart accelerates down a hill? If yes, state your result in the most general terms supported by your analysis. If no, describe how you would convince your friend. What are the limitations on the accuracy of your measurements and analysis?

Appendix G

Distributions of Student Responses to Survey Questions

Appendix G.1

Percentage Responses to Nine Attitude Questions about the Course Components, by Treatment

1. The lectures were a waste of time.	Computer Treatment	Traditional Treatment
Strongly Disagree	9	10
Disagree	67	51
Neutral	47	47
Agree	30	35
Strongly Agree	20	25

2. The lectures helped to clarify ideas from the text.	Computer Treatment	Traditional Treatment
Strongly Disagree	10	20
Disagree	38	43
Neutral	59	48
Agree	59	52
Strongly Agree	7	5

3. The main points of the lecture were clearly stated and emphasized.	Computer Treatment	Traditional Treatment
Strongly Disagree	16	16
Disagree	44	48
Neutral	45	45
Agree	50	54
Strongly Agree	18	5

4. Solving problems with my group helped me to understand the course material.	Computer Treatment	Traditional Treatment
Strongly Disagree	10	9
Disagree	20	19
Neutral	21	28
Agree	87	92
Strongly Agree	35	20

5. The discussion sections were a waste of time.	Computer Treatment	Traditional Treatment
Strongly Disagree	25	25
Disagree	82	78
Neutral	35	38
Agree	20	18
Strongly Agree	10	9

6. The discussion problems provided useful guidance for solving problems on the individual exams.	Computer Treatment	Traditional Treatment
Strongly Disagree	14	13
Disagree	33	32
Neutral	41	37
Agree	74	74
Strongly Agree	11	12

7. The laboratory problems provided useful guidance for solving problems on the individual exams.	Computer Treatment	Traditional Treatment
Strongly Disagree	26	20
Disagree	53	62
Neutral	33	44
Agree	53	41
Strongly Agree	8	1

8. The laboratory problems helped me to understand the concepts covered in class.	Computer Treatment	Traditional Treatment
Strongly Disagree	15	10
Disagree	24	29
Neutral	49	44
Agree	76	82
Strongly Agree	9	3

9. The laboratory sessions were a waste of time.	Computer Treatment	Traditional Treatment
Strongly Disagree	20	18
Disagree	78	70
Neutral	37	50
Agree	22	18
Strongly Agree	16	12

Appendix G.2

Percentage Responses to Nine Group Behavior Questions, by Treatment

1. Our group discussed equipment difficulties.	Computer Treatment	Traditional Treatment
Hardly Ever	10	5
Not Very Often	33	18
Sometimes	74	56
Quite Often	43	64
Almost Always	13	25

2. Our group discussed misunderstanding about the physics.	Computer Treatment	Traditional Treatment
Hardly Ever	5	6
Not Very Often	21	23
Sometimes	64	74
Quite Often	71	54
Almost Always	12	11

3. One person in our group did most of the data analysis.	Computer Treatment	Traditional Treatment
Hardly Ever	14	25
Not Very Often	64	69
Sometimes	49	45
Quite Often	36	26
Almost Always	10	3

4. I felt I was contributing to our group's solution to the lab problem.	Computer Treatment	Traditional Treatment
Hardly Ever	2	3
Not Very Often	5	4
Sometimes	36	31
Quite Often	84	92
Almost Always	46	38

5. Our group worked efficiently.	Computer Treatment	Traditional Treatment
Hardly Ever	4	1
Not Very Often	11	12
Sometimes	63	57
Quite Often	78	77
Almost Always	17	21

6. I felt the other members of my group were contributing to the solution of the lab problem.	Computer Treatment	Traditional Treatment
Hardly Ever	4	2
Not Very Often	9	4
Sometimes	35	27
Quite Often	96	111
Almost Always	29	24

7. Our group did most tasks together.	Computer Treatment	Traditional Treatment
Hardly Ever	3	2
Not Very Often	10	10
Sometimes	44	36
Quite Often	89	101
Almost Always	27	19

8. Our group divided most tasks.	Computer Treatment	Traditional Treatment
Hardly Ever	11	2
Not Very Often	32	27
Sometimes	69	56
Quite Often	48	62
Almost Always	13	21

9. Our group communicated well with each other, so each member understood what the heck was going on.	Computer Treatment	Traditional Treatment
Hardly Ever	6	2
Not Very Often	11	12
Sometimes	40	47
Quite Often	93	89
Almost Always	22	18

Appendix G.3

Percentage Responses to Six Attitude Questions about the Laboratory Tools, by Treatment

1. Although it took time to learn to use spark tape (VideoTool), it was time well spent.	Computer Treatment	Traditional Treatment
Strongly Disagree	9	17
Disagree	23	33
Neutral	52	55
Agree	73	54
Strongly Agree	14	9

2. Analyzing spark tape data and Polaroid film (Using VideoTool) taught me the importance of selecting an appropriate origin and / or axis and meaningful units in solving problems.	Computer Treatment	Traditional Treatment
Strongly Disagree	13	11
Disagree	38	28
Neutral	48	57
Agree	61	61
Strongly Agree	11	11

3. Analyzing spark tape data (Using VideoTool) helped me understand the equations I used in class.	Computer Treatment	Traditional Treatment
Strongly Disagree	19	14
Disagree	45	29
Neutral	41	48
Agree	58	66
Strongly Agree	7	11

4. Analyzing spark tape data (Using VideoTool) helped my understanding of derivatives.	Computer Treatment	Traditional Treatment
Strongly Disagree	36	26
Disagree	45	46
Neutral	43	54
Agree	35	36
Strongly Agree	10	6

5. I found doing the data analysis in lab with my group (I found the printed graphs and equations) useful in writing my lab reports.	Computer Treatment	Traditional Treatment
Strongly Disagree	9	7
Disagree	20	16
Neutral	15	32
Agree	80	94
Strongly Agree	47	19

6. I am looking forward to using spark tapes/Polaroid film (VideoTool) in my next physics class.	Computer Treatment	Traditional Treatment
Strongly Disagree	21	46
Disagree	14	49
Neutral	56	46
Agree	64	18
Strongly Agree	15	9