

**COMPUTER-RELATED TECHNOLOGY USE IN THE HIGH SCHOOL
PHYSICS CLASSROOM: A CASE STUDY**

by

Patricia Head McClure

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
DOCTOR OF EDUCATION

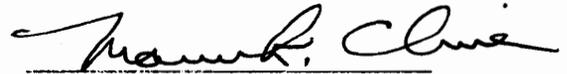
in

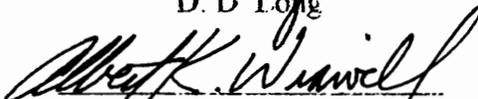
Curriculum and Instruction

APPROVED: 
T. E. Gatewood, Co-Chairman


T. G. Teates, Co-Chairman


D. D. Long


M. G. Cline


A. K. Wiswell

November, 1996
Blacksburg, Virginia

Key Words: Technology, Physics, Instruction, Teachers, High School

c.2

LD
5655
V856
1996
M386
c.2

COMPUTER-RELATED TECHNOLOGY USE IN THE HIGH SCHOOL PHYSICS CLASSROOM: A CASE STUDY

by

Patricia Head McClure

Committee Chairpersons: Thomas E. Gatewood and Thomas G. Teates
Curriculum and Instruction

(ABSTRACT)

This research explored the high school physics classroom environment when computers and other technology were integral components of the curriculum. The unit of analysis was one high school physics teacher and his regular and honors classes. The main research was conducted in an inductive, qualitative manner that examined the processes involved. Videotapes and audiotapes were made of classroom activities. Dialogs of students and the teacher were recorded and analyzed, revealing ways in which students use technology to learn physics and to solve problems. In addition, results of the *Force Concepts Inventory* were analyzed to add a quantitative dimension to the research.

The research found that, in this classroom, technology enabled the teacher to plan and conduct a creative, enjoyable introductory physics program. The teacher selected from a plethora of resources--*Mechanical Universe High School Adaptation* videotapes,

videodiscs, Vernier and Pasco probeware, and software which included *Interactive Physics II™*, *Physics Explorer*, *ClarisWorks*, and *CA Cricket Graph*. A ratio of 3 students to 1 computer allowed groups of students to engage actively in the learning process.

The combination of technology and collaborative learning made a powerful learning experience for the physics students. The technology provided many teachable moments because the teacher was freed from whole-class instruction to concentrate on individuals and small groups. The teacher developed skill in using technology over a period of three years. He continues to develop as new instructional technology becomes available and as he understands more about how students learn. Learning to use technology effectively in the classroom is a process that occurs over a long period of time; it is not an event.

School administrators, school system administrators, and producers of physics instructional technology and textbooks can learn from this study. School administrators must be supportive of risk-taking teachers. They need to develop teacher performance standards that recognize the classroom practices and mentoring efforts of exemplary technology-using teachers.

School districts can help remove barriers to instruction by infrastructure support--renovating buildings with electrical and network wiring, providing dynamic continuous staff development for teachers and administrators, and contracting for schoolwide or districtwide software agreements and equipment maintenance.

DEDICATION

I want to dedicate this dissertation to my family--my husband, Tom McClure; my daughter, Danielle McClure; my mother, Lucille Head; and my sister, Johnna Head—who have prayed for me, have cried with me, and now can celebrate with me. It is also dedicated to the loving memory of my father, John Head.

Tom, my husband and my best friend in life, has been a source of strength and encouragement. He has read every word that is in this dissertation and many others that did not make it to the completed document. He has rescued me more than once from a computer crisis. He has helped me word process documents long into the night.

I want to thank my daughter, Danielle, who has spent her high school and college career with Mom in a doctoral program. I have tried very hard to balance my time and to give you the time and energy you deserve from your Mom. Danielle, please forgive me where I have failed.

I want to thank my Mother, Lucille Head, without whose help I could not have made it through. Mom and Dad instilled in me a desire to learn and to work. They gave me a love of education and a love for science that is my in very heart and being.

Finally, I want to thank my sister, Johnna, who came to help me when I was recovering from cancer in the midst of this dissertation. She encouraged me to keep on going.

ACKNOWLEDGMENTS

Completing this dissertation has been one of the most challenging and personally rewarding events in my life. I have benefited professionally as I have studied and worked directly in the classroom with the outstanding teacher who was the focus of this study and with his physics students. This process has been done with the support and encouragement of many individuals without whom I could not have completed this work.

I want to express my appreciation and gratitude to Dr. Tom Gatewood and to Dr. Tom Teates who co-chaired my dissertation committee. Dr. Gatewood helped me to construct my program of studies and gave me the vision from the beginning of my study to complete it. Dr. Tom Teates is a fine science educator who helped me formulate the research questions. Even though he has retired from Virginia Polytechnic Institute and State University, he has remained as my co-chair. He has been faithful to encourage me, to read my work in progress, and to give me feedback as I moved closer to my goal.

I also want to thank the other members of my dissertation committee for their support. Dr. Jerry Cline, Dr. Dale Long, and Dr. Bert Wiswell were available to talk to me and were helpful in giving me suggestions and encouragement. Dr. Dale Long guided me in looking closer at students in the classroom and in the physics concepts they were learning. Dr. Wiswell encouraged me to think of physics as a foundational course for all students including those who have traditionally not taken physics. Dr. Jerry Cline spent untold hours helping me develop and refine the qualitative research plan. He listened, read

my transcribed notes, and helped me to gain insights into the data. Without the guidance of these fine men, I would not have completed this dissertation.

I would like to thank the people in the school district who have allowed me to gather the information, the teacher who trusted me enough to allow me to tape his classes for seventeen days over a three month-period of time, and the students who accepted me as I taped their conversations and actions.

Special recognition goes to two of my peers, Jackie Boddie and Lorraine Walker, who shared this two-year experience with me through a seminar study group. Many afternoons and evenings have been spent reading each other's writings and helping in planning the next phase of our studies. They helped to keep me on track by making me explain more clearly in a layperson's terminology the physics activities that were occurring in the classroom. Thank you ladies.

Finally, I wish to thank two of my friends, Jan Tuomi and Karen McMeekin, who edited portions of this document and gave me constructive feedback.

TABLE OF CONTENTS

LIST OF TABLES	xi
LIST OF FIGURES.....	xii
CHAPTER 1: INTRODUCTION	1
Purpose of the Study	5
<u>Limitations of the Study</u>	6
<u>Research Questions</u>	7
Description of the Problem	8
CHAPTER 2: LITERATURE REVIEW.....	11
Teaching Practice Incorporating Instructional Technology.....	11
Computers in Science	16
Assessment of the Effectiveness of Instructional Technology	24
The Link Between Technology and Restructuring.....	25
Reason for Case Study Research in Physcis Education.....	30
CHAPTER 3: METHOD.....	39
Case Study Research	33
Acquiring Knowledge of Student Understanding and Learning.....	42
Why an N of One?.....	44
Why This Teacher?.....	46
Why This School?	47
Research Plan.....	47

TABLE OF CONTENTS

<u>Classroom Data Collection Technique</u>	48
<u>Data Analysis Process</u>	49
CHAPTER 4: FINDINGS	53
Analysis of Qualitative Research.....	54
The Hardware, Software, and Other Resources	55
Examples from the Technology-Rich Classroom	58
<u>Example of Physics Explorer Simulation, Study of Orbital Motion</u>	61
<u>Example of Interactive Physics II™ Simulation, Study of Momentum</u>	73
<u>Example of Computer-Based Probeware Experiment,</u> <u>Impulse and Momentum</u>	81
<u>Example of Computer-Based Probeware Experiment,</u> <u>Smart Pulley Lab on Impulse, Momentum, Work, & Energy</u>	94
<u>Summary of Examples From the Technology Rich-Classroom</u>	124
<u>The student’s role</u>	124
<u>The teacher’s role</u>	127
<u>New and unique learning opportunities</u>	130
Analysis of the <i>Force Concept Inventory</i>	131
<u>Kinematics</u>	133
<u>First Law</u>	134
<u>Second Law</u>	138
<u>Third Law</u>	139

TABLE OF CONTENTS

<u>Superposition Principle</u>	140
<u>Kinds of Force</u>	140
<u>Questions of Validity of FCI</u>	142
CHAPTER 5: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS ...	149
Summary.....	150
Conclusion	159
Discussion and Recommendations	160
<u>Significance for Students</u>	161
<u>Significance for Teachers</u>	163
<u>Student Misconceptions in Physics and Instructional Technology</u>	163
<u>Willingness to Change and Time for Change</u>	165
<u>Assessment of Students</u>	165
<u>Teacher Directions to Students and Handouts</u>	166
<u>Organization and Classroom Management</u>	167
<u>Planning a Technology-Rich Physics Program</u>	168
<u>Significance for School Administrators</u>	169
<u>Evidence of Computer Use</u>	169
<u>Administrative Support for Technology-using Teachers</u>	170
<u>Significance for School System Administrators</u>	172
<u>Hardware</u>	172

TABLE OF CONTENTS

<u>Software</u>	173
<u>Maintenance and Replacement</u>	174
<u>Staff Development</u>	175
<u>Block Scheduling and the Use of Instructional Technology</u>	178
<u>Facility Renovations</u>	178
<u>Significance for Publishers and Producers of Instructional Technology</u>	180
Ideas for Further Study.....	182
LITERATURE CITED.....	184
APPENDIXES.....	193
Appendix A: Narrative of Preliminary Study.....	194
Appendix B: Consent Forms.....	209
Appendix C: Interview Questions.....	213
Appendix D: Sample of Ethnograph V4.0 Code Word Dictionary.....	216
Appendix E: Resources Used in Physics Classroom.....	235
Appendix F: Force Concept Inventory.....	241
VITA.....	247

LIST OF TABLES

Table 1: <u>Hardware Used in Physics Classes During Study</u>	57
Table 2: <u>Software Used in Physics 1 and Physics 1 GT Classes During the Study</u>	59
Table 3: <u>Symbols and Terms Used in Smart Pulley Lab</u>	95
Table 4: <u>Three Readings from Smart Pulley Data Table</u>	97
Table 5: <u>Newtonian Concepts on the Force Concepts Inventory</u>	135
Table 6: <u>Misconceptions</u>	136
Table 7: <u>Selected Questions from the Force Concept Inventory</u>	146
Table 8: <u>Technology-Related Staff Development Courses for Physics Teachers</u>	177
Table 9: <u>Software Resources in Classroom</u>	236
Table 10: <u>Videodisc Resources in Classroom</u>	238
Table 11: <u>Textbook Resources for Students:</u> <u>Class Sets of High School Physics Books</u>	238
Table 12: <u>Textbook References for the Teacher</u>	239
Table 13: <u>Probeware Resources in Classroom:</u> <u>Probeware Sold by Vernier Software</u>	240

LIST OF FIGURES

- Figure 1. Meters or variable input windows, graph window, and model window of *Physics Explorer: Gravity, How “Heavy” Is a Planet* screen. 62
- Figure 2. Screen display from *Interactive Physics II™ Simulations: Rocket Sled I*, by Addison-Wesley Publishing Company, Inc. 75
- Figure 3. Drawing represents photogates and dynamics carts on a table with cable connections to ULI and computer 83
- Figure 4. Drawing of cart, Smart Pulley, and hanging mass. 97
- Figure 5. Diagram of physics classroom. 128

CHAPTER 1

INTRODUCTION

The last fifteen years have brought many changes in the technology used in American homes, schools, and businesses. Informational technology and computers are changing every aspect of human life—the way we learn, play, shop, work, and communicate. “Technological literacy—meaning computer skills and the ability to use computers and other technology to improve learning, productivity, and performance—has become as fundamental to a person’s ability to navigate through society as traditional skills like reading, writing, and arithmetic” (U.S. Department of Education, 1996, p. 1).

Cuban (1986) characterized the 1980s as the decade of the computer and others wrote about the potential of the computer in education (Papert, 1980; U.S. Congress Office of Technology Assessment, 1988, 1995; U.S. Department of Education, 1996). The 1990s brought the realization that computers alone will not create educational reform. Sheingold (1990) encouraged the bringing together of three agendas—an emerging consensus about learning and teaching, well-integrated uses of technology, and restructuring. The claims of the past about the importance of technology are being “widely tempered by an understanding that it is not the features of the technology alone, but rather the ways that these capacities are put to use in human environment that shape their impact” (p. 12). The sheer growth in the numbers of computers over the last fifteen years is impressive.

In the 1980s, computer-based technology dramatically increased in schools across the United States. The Office of Technology Assessment (OTA) estimated that schools with one or more computers grew from 18% in 1981 to 95 % in 1987. By 1992, the number of computers in schools reached 4.4 million and 98% of schools had one or more computers (Quality Education Data [QED], 1992). QED estimates that the number of computers in pre-college education has been growing at 10% per year. In 1984-85, there were 75 students per computer and by 1994, the ratio dropped to 12 students per computer—a growth of more than 300% (QED, 1994-95).

According to OTA (1995), schools in the United States were projected to have 5.8 million computers, or one for every nine students, by spring 1995. Even though the number of computers has increased greatly over the last fifteen years, the U.S. Department of Education (1996) estimated that “4 percent of schools have a computer for every five students” (p. 5).

The dollar investment by school districts in technology has continued to increase yearly. Anderson (1993) estimated that districts in 1993 spent over \$1 billion on hardware and software, about a half of one percent of the average \$5,500 per pupil cost. The U.S. Department of Education (1996) estimated that in school year 1994-1995, the expenditure had risen to \$3.3 billion. The vision of the Technology Literacy Challenge of President Clinton and Vice President Gore, in which all students will be technologically literate in the 21st century, will cost the American people somewhere between \$50 billion and \$109 billion and take five to ten years to complete. The wide discrepancy in cost estimates is

due to many variables including the number of computers per classroom, the hardware and software costs, teacher training costs, infrastructure improvement costs, and the replacement costs of the multiple levels of current technology. Whatever the cost, it is evident that computers have become a part of American life and education.

As the number of computers and the dollar investment increase, the way computers are being used in education is changing (Becker, 1993a). The shift has been away from teaching students to program computers to teaching students to use computer tools. Becker spent the last decade conducting national surveys about the instructional uses of school computers. In 1983, he found that programming and computer literacy activities (learning about computers) constituted 75% of all computer use by secondary students. In 1985, programming took 45% of the computer time. By 1989, programming decreased to 20% of the time; learning word processing and database programs and keyboarding skills increased to 30% of a student's computer usage time. The actual use of "computer applications such as word processing and 'databases'... was a major focus in more than 80% of high school classes" (Becker, 1993b, p. 71). Although computer use has the potential to change instruction and learning in the science, social studies, and math classes, Becker's 1989 survey found that it was more common for math and science teachers to use the computer for word processing than for any specific science or math application. He concluded that it appears that secondary school students are closer to mastering word processing than to attaining more computationally and cognitively complex skills.

Computer use by exemplary teachers in science and math is more complicated than merely word processing. Most American high school science and math teachers still do not use computers at all. Anderson (1993) found in a 1991-92 national survey that, although 97% of 11th grade students took one or more math and science courses, only 44% had used a computer in any course and only 23% had used a computer more than once or twice. Becker (1994) reported that only 1% of computer-using science teachers used interfacing probeware five or more times per year. The use of computers with a combination of interfacing probeware, simulations, databases, spreadsheets, word processing, graphing, and tutorial programs in science classrooms has not been studied because so few science teachers use computers as a teaching tool in their practice of teaching.

Computers can be used in the science classroom to communicate information by use of word processing, telecommunications, and graphing programs; to collect and analyze data with interfacing laboratory devices; to simulate experiments that are otherwise impossible to conduct in the classroom; to organize data in meaningful ways with databases and spreadsheets; to study new information with tutorial programs; and to restudy information with drill and practice programs. Computers can be used with telecommunication software, CD-ROMs, or videodiscs to access images that can be used to study phenomena as diverse as Jupiter's lunar volcanic activity and the DNA of cells.

Although hardware and software are important, the premier importance of the teacher in innovation and change has been expressed by many (Becker, 1994; Cuban,

1989; Hadley and Sheingold, 1993; Hass, 1993; LaFrenz and Friedman, 1989; Sheingold and Hadley, 1990). Dale LaFrenz and Jo Elise Friedman (1989) expressed the importance of teachers, “Computers Don’t Change Education, Teachers Do!” Cuban (1989) described the teacher as a “gatekeeper” for educational change and emphasized that the role of the teacher is critical in establishing a suitable learning environment. In the *Report on the Effectiveness of Technology in Schools 1990-1994*, Sivin-Kachala & Bialo (1994) examined research studies on the effects of technology on interactions involving teachers and students in the learning environment. They concluded that current research underscores “the importance of the teacher’s role in creating an effective, technology-based learning environment—an environment that is characterized by careful planning and frequent interaction among students and the teacher” (p. 25).

Purpose of the Study

This research study explored the high school physics classroom environment when computers and other technology were an integral part of the classroom and the curriculum. The unit of analysis was one teacher and his introductory physics classes. The research was conducted in an inductive, qualitative manner that sought to examine the processes involved. The researcher attempted to describe what was happening in the classroom by describing and analyzing the student-student interactions with technology, student(s) and teacher interactions with technology, and the holistic classroom environment. This complex study did not manipulate variables but asked, “What is happening in this classroom at this point in time?” The research provided a rich, in-depth

description of how an experienced teacher adapted the use of hardware (computers, videodisc player, videotape player, laser printer, and scanner), probeware, and software (simulation, tutorial, HyperCard, graphing, word processing, database, and spreadsheet) in the high school introductory physics curriculum. In addition, the research analyzed and described the teaching methods and classroom management techniques that were being used in the overall instructional program.

This research focused on the interaction of the teacher, the students, and the technology as the teacher guided the instruction based on his formative assessment of students' understandings of physics. This interaction took place in the context of a technology-rich classroom which utilized computers, CD-ROMs, and videodisc and videotape players along with traditional physics apparatus. This afforded the researcher the opportunity to observe and record the potential for teaching and learning influenced by the technology. Student progress in the study of physics was monitored as topics in kinematics, dynamics, electricity, and magnetism were studied.

Limitations of the Study

A single case was studied in context. The study included surrounding influences such as involvement of the teacher in school management; interaction and support of school and school district administrators; interaction and involvement of the teacher with other teachers and student-teachers or interns; and interaction with technical support personnel at the local and at the national level. The central study examined the interaction among the students, the teacher, and the technology.

The study was conducted during a three-month period of time that corresponded to six months in a traditional classroom. The school was on a semester-semester block schedule in which students complete four high school credits during each semester. The new semester (i.e. new course) began February 1 and the researcher began the field study in April and finished in early June.

Due to circumstances beyond the control of the researcher, the first few weeks of the semester were not studied. This was an intensive time of technology use in which computers, motion detectors, and simulations were used in the study of kinematics. A few studies have reported on the use of computer technology in the study of kinematics (Thornton, 1989, 1992; Thornton & Sokoloff, 1990). The research in this study began as the students were completing the study of orbital motion and ended as they finished the study of electricity and magnetism.

Research Questions

This study addressed the following questions.

1. What is the daily teaching practice of this experienced computer-using high school physics teacher?
2. What are this teacher's expectations of students and instructional technology?
3. What are the physics classroom processes and interactions when computers are used to teach high school students?
4. What barriers and support mechanisms affect the use of technology in this physics classroom?

5. How do the students, the teacher, and the technology interact in the learning environment?
6. What is the unique contribution of computer-related technology to student-teacher and student-student interactions? Are there cognitive representations of computer output that make interaction different from traditional lecture and laboratory methods?
7. How do the interactions between the teacher, students, and technology affect student conceptual understanding?

Description of the Problem

Several researchers have turned their attention to classroom teachers and how these teachers are integrating computers into their classroom practice (Becker, 1994; Bradley, 1992; Bradley & Morrison, 1991; Dwyer, 1994; Dwyer, Ringstaff, & Sandholtz, 1990a, 1990b; Hadley & Sheingold, 1993; Hass, 1993; Marcinkiewicz, 1993/94; Naimi, 1990; Ringstaff, Sandholtz, & Dwyer, 1990; Sandholtz, Ringstaff, & Dwyer, 1990a; Sheingold, 1990, 1991; Sheingold and Hadley, 1990). Olson (1988) wrote that one of the research goals of the nineties will be to understand how teachers use computers in their practice and how the presence of computers impacts upon the social organization of the classroom. Marcinkiewicz (1993/94) says that we “need to study teachers and what makes teachers want to- or need to- [sic] use them [computers]” (p. 234).

Many elementary teachers and a few secondary teachers have been studied; however, no studies were found in the literature on (1) the physics classroom environment in which multiple uses of the computer were studied, (2) the teaching practice of

computer-using physics teachers, and (3) the interactions of physics students with fellow students, the teacher and technology in simulation and probeware laboratory activities.

Prior research has not concentrated on the teaching practice of computer-using science teachers, but a few studies have included teacher change (Bly, 1993; Hakerem, Dobrynina, Hurwitz, Shann, & Shore, 1993). There are a few studies of the classroom practices of experienced computer-using elementary teachers (Bradley, 1992; Conery, 1993; Hass, 1992). Conery (1993) studied teacher beliefs about computers in the elementary classroom in three case studies. Hass (1993) explored the understandings of the elementary teacher and the practice of teaching with an infusion of computers. Bradley (1992) studied teacher-student interactions in upper-elementary classrooms with computers and in computer labs.

The research on computer use in science education has primarily concentrated on student achievement and on the use of the microcomputer-based laboratory (MBL) to improve student conceptual understanding of physics. Research studies have shown that the well-designed science laboratory with computer-based sensors or probes can provide students with rich experiences that are necessary to develop their conceptual understanding of physics, particularly motion and thermodynamics (Eylon & Linn, 1991; Layman, 1984; Layman & Krajcik, 1992; Linn, 1991; Linn and Songer, in press a, in press b; Linn, Songer, Lewis, & Sterne, in press; Thornton, 1989, 1992). Kelly and Crawford (1996) found that the MBL helps students link oscillatory motion with graphical representations.

Spreadsheet programs, interactive video, and simulations are also used in physics and have been found to enrich the learning environment and contribute to student achievement (Hoffer, Radke, & Lord, 1992; Ronen, Langley & Ganiel, 1992; Roth, 1995; Trumer, 1994). Roth (1995) studied conversations as his students worked on Interactive Physics™.

The MBL, spreadsheet programs, interactive video, and simulations were components of this teacher's physics program. In the school district of the case study, three pilot sites were established in 1991 to integrate computers into the teaching practice of six physics teachers at three high schools. The science curriculum specialist and the physics teachers in the original 1991 pilot schools evaluated software and probeware for cost effectiveness and usefulness in introductory physics.

In 1993, physics computer labs were established in all of the district's high schools. A physics computer lab consisted of ten student Macintosh stations, one teacher Macintosh station, a large screen monitor, a laser printer, MBL probes (probeware), videodiscs, and software. The pilot teachers had, over the past three years prior to this study, learned to utilize the computer-related technology as instructional tools. They had progressed from being novices in the use of instructional technology to being adapters and innovators. Although informal evaluations of the pilot sites were conducted, an in-depth study has not been conducted. This research focused on the teaching practice of one of the experienced pilot teachers who used computers in various ways to teach students physics.

CHAPTER 2

LITERATURE REVIEW

In the review of literature, the researcher discusses the issues associated with teaching practices which incorporate instructional technology, research on using computer-based instruction to teach students science, assessment of the effectiveness of instructional technology, the link between technology and restructuring, and the use of case study research in education.

Teaching Practice Incorporating Instructional Technology

The process of change has been reflected in recent research that examines changes in teaching practice of computer-using teachers. The teacher has been called the gatekeeper to an innovational change (Cuban, 1989). Once computers are in the schools, it is important to look at the factors that contribute to successful use by teachers and students. "Computers in themselves do not automatically change the nature of teaching and learning, rather it is the way teachers integrate computers into classroom, the content of technology-aided lessons, and the quality of the software programs selected that determine whether and how computers in schools really benefit students" (Woronov, 1992, p. 1).

U.S. Congress's OTA 1995 report, *Teachers & Technology: Making the Connections*, concluded that trained teachers are more likely to use technology when they understand how it can help them be more productive, thus doing a better job teaching

students . “Helping teachers may, in fact, be the most important step in helping students” (p.88).

Maor and Taylor (1995) studied seven teachers in Australia, two of them intently, and found that the teacher’s epistemologies strongly influenced the development of higher level thinking skills in students who used the *Birds of Antarctica*, a computer database. In a highly controlled, transmissionist environment, only a few students made a transition toward developing higher-level thinking skills. In contrast, “The teacher’s constructivist-oriented pedagogy enabled the majority of students to develop higher-level thinking skills such as thinking critically, asking creative questions, and undertaking inquiry-oriented problem solving” (p. 852).

In a meta-analysis of forty primary research studies of computer use in elementary schools (grades K-6) since 1984, Ryan (1990) concluded that student achievement is linked to teacher training, personal, and social components. Five or more hours of teacher computer training was found to be a significant indicator of student academic achievement. “The presence of social factors appeared to be related to increased academic achievement. Among these were social interaction between the teacher and students, among students (cooperative learning), and between the trainer/researcher and teacher” (p. 104). Personal learning such as self-directed, self-expressive, and guided discovery was an important factor in student achievement.

The development of teacher expertise in utilizing computer-related technology in the classroom takes time and support. (Becker, 1991, 1993a, 1993b; Dwyer, Ringstaff, &

Sandholtz, 1990a, 1990b; Hadley and Sheingold, 1993; Sandholtz, Ringstaff, & Dwyer, 1990b; Sheingold and Hadley, 1990; Stearns, David, Hanson, & Schneider, 1991).

Sheingold and Hadley (1990) report that their data suggest five or six years for teachers to develop a deep level of comfort with computers and knowledge about using computers for teaching. Stearns and others (1991) reported that after three years of using computers and participating in intensive professional development opportunities in a model technology program in Cupertino Union School District and Fremont Union High School District, “Most classroom uses are not yet sufficiently pervasive or different from previous practice for us to see overall effects on students’ academic achievement” (p. 8).

Analysis of data from a four-year study of the Apple Classrooms of Tomorrow (Dwyer, Ringstaff, & Sandholtz, 1990a, 1990b) has identified five Stages of Teacher Development—entry, adoption, adaptation, appropriation, and invention—and three Stages of Classroom Management—survival, mastery, and impact. Teachers in this technology-rich supportive pilot study, sponsored by Apple Computer, Inc., went from entry level to appropriation and survival to impact in two years. Innovation and change in teaching styles occurred over a long period of time, and the change began to occur after the students and teachers had personally appropriated the technology tools.

Bradley (1993), Dwyer, Ringstaff, and Sandholtz (1990a, 1990b), Hadley and Sheingold (1993), Sandholtz, Ringstaff, and Dwyer (1990a), and Swan and Mitrani (1993) reported that interactions in a technology-rich classroom become more collaborative and student-centered, and the teacher becomes a facilitator of learning. Although current

research indicates that students learn best by constructing their own meaning, many teachers continue to plan and deliver content lectures with little opportunity for students to personalize the learning. Too often facts are memorized and repeated on tests.

Businesses tell educators that they need people who can work together on teams, know how to use technological tools, and can think creatively to solve problems. We need more exemplary teachers who can use technology in their teaching practice.

Becker (1993b), through analysis of questionnaires, deduced that there are factors that help to produce exemplary technology-using teachers—"colleagueship among users, school support for using computers for 'consequential activities,' resources allotted to staff development and computer coordination, principals concerned about equity of access, and [allocated resources for software and] smaller class sizes"(p. 1). Becker identified 45 teachers, out of the 516 surveyed, that he classified as "exemplary" due to their responses as compared to "standards." Becker estimated that in 1993 only 3% of the teachers in the U.S. were exemplary in the use of instructional technology.

Sheingold and Hadley (1993,1990) studied reputationally exemplary computer-using teachers of grades 4 to 12 from across the United States. In a national survey, 608 respondents answered questions about their current teaching practices, barriers to computer integration in the past and present, incentives to integration, perceived changes in teaching practice with technology, descriptions of staff development and experience, and demographic data. The results revealed that even though the teachers were unique in their involvement with technology, neither they nor their schools were skewed

demographically. The average number of computers in the schools was twice the national average, 59 versus 26. Teachers in 90% of the schools had used computers for instruction for four or more years, 75% for five or more years, and some for as much as ten years. More than 43% of the teachers in these schools used computers. More than half of the teachers were between 40 and 49 years old, and 75% had been teaching for thirteen years or more. These teachers had taken advantage of staff development opportunities, both in-service and on their own time. Sixty percent had taken district in-service classes and 40% had taken graduate or undergraduate courses. Ninety percent got information from software catalogs, computer magazines, computer education magazines, and conferences related to computer education. Eighty percent got information from district workshops or materials supplied by the district. Eighty percent of the teachers had computers at home. These teachers had actively pursued learning about the technology and had taken advantage of educational opportunities.

Teachers in the Hadley and Sheingold study (1993) had local support in the form of peer teachers, computer coordinators or aides, and other consultants. One of the surprising results was that the teachers used computers for an average of 14 to 15 different practices. The word processor was the most used tool (90 % of classes) and had become part of many curricula including language arts, science, and social studies.

For the most part, computers are not currently integrated into the instructional practice of teachers (Becker, 1993a, 1993b; Hadley & Sheingold, 1993; Marcinkiewicz, 1993/94; U.S. Congress's OTA, 1988, 1995; U.S. Department of Education, 1996). They

generally provide workbook-like activities or other peripheral activities. True integration of computers requires teachers who are innovative, flexible, and willing to risk.

Marcinkiewicz (1993/94) found that only 8% of the 170 elementary teachers surveyed integrated computers into instruction although the computers were available at an acceptable ratio (1: 44 or better) and had been in the school for three or more years. Nearly half of the teachers in the study never used computers at all and 47% were at the “utilization” stage. Marcinkiewicz identified four stages of computer utilization—Nonuse, Utilization, Integration, and Evolution. None of the teachers were at the evolution stage in which they had fully integrated computers into their teaching practice and “remain sensitive to, be prepared for, and be able to adapt to change” (p. 222).

Computers in Science

Becker (1993) called for schools to increase their efforts to integrate computers into the academic curricula, particularly math and science. In Becker’s (1991) 1989 survey of computer-using teachers, he found that the “teachers’ goals were partly a function of the conditions under which they use computers, how many computers they had available, and whether they [computers] were able to be used in their own classroom or were in a shared computer lab” (p. 23). He found that when computers were used in high school science, the software programs used more than 5 times by students were—drill and practice, 18%; tutorials, 7%; spreadsheet/database, 4%; programming languages, 3%; word processing, 10%; simulations, 11%; and lab interfacing, 1%.

Becker (1993) analyzed computer use in math and science instruction over the last decade and predicted the changes that will occur in the 1990s. "The 1980s were a decade for exploration in the use of computers in math and science instruction. Insufficient hardware, somewhat limited software, and few models for integrating computer work with regular math and science curricula all limited the importance that computers had for student learning. The 1990s promise to be different in at least two ways: (1) more numerous and more powerful computers and (2) more sophisticated software will come to be used. Major changes in math and science curricula are likely to make computers more relevant and more naturally integral to instruction activities in those subjects" (p. 25).

Although only 1% of computer-using science teachers used lab interfacing (also called sensors, probeware, and MBL) equipment more than five times (Becker, 1991, 1993), students who used lab interfacing materials have illustrated an understanding of physics concepts. Thornton (1989) found, "Students who use the MBL materials show substantial and lasting understanding of basic physical concepts not learned by a majority of students in standard physics courses" (p. i). Thornton (1989) reminded us that research (Clement & Lochhead, 1979; Fisica nella Scuola, 1986; Holloun & Hestenes, 1985; McCloskey, Caramazza, & Green, 1980; Thornton, 1989) has shown the majority of students' misconceptions remain unchanged after the usual physics instruction. "The principal problem is that a majority of our students do not understand physics when they finish our courses" (p. 1).

The constructivist foundation of the MBL is inquiry-based instruction in which students think critically and develop concepts on their own. Constructivists hold that students learn best by actively engaging in the learning in a rich environment where they can question, construct knowledge, and communicate their understandings. Students who engage in planned learning activities do not see science as facts and formulas but as a process. Students have views about many topics in science from an early age. While these views often differ from scientists' views, they make sense to the student. Students' views are not always influenced by teaching in the way teachers hope (Harlen, 1985; Osborne & Freyberg, 1985).

When teachers plan lessons, they need to consider what pre-conceived ideas their students have. "We need to appreciate that direct teaching can have surprisingly little affect [sic] on these ideas" (Osborne in Harlen, 1985, p. 82). Students must be actively involved in the learning process, and they need to communicate with their peers and the teacher about the process of learning itself (Thornton, 1992, 1989).

Thornton (1992) reported on the outcome of the August 1992 meeting of the New Mechanics Advisory Group, as they looked at methods of physics teaching that have been shown to enhance student learning. He cited research of Laws, Sokoloff, and Hestenes, as he concluded: "These studies agreed on several important points regarding traditional physics instruction: (1) While rote use of formulas is common, a coherent conceptual framework is not typically attained; facility in solving standard quantitative problems is not an adequate criterion for functional understanding. (2) Growth in reasoning ability does

not usually result from traditional instruction. (3) Connections among concepts, formal representations (algebraic, diagrammatic, graphical), and the real world are often lacking. (4) Teaching by telling is an ineffective mode of instruction for most students” (pp. 42-43).

Technology, particularly microcomputer based laboratory (MBL) tools, can enable students to actively construct knowledge by manipulating physical objects, gathering, displaying, and interpreting data. Physics probeware (sensors) can measure physical quantities such as temperature, position, velocity, acceleration, force, magnetic field, sound, pressure, light, radiation, potential difference, and current. The software associated with these probes allows students to display the data in real-time in a graph or data table. The data can be saved, printed, analyzed, and displayed. The use of MBL (probeware) encourages inquiry and a constructivist approach to learning science (Thornton, 1989).

Thornton at Tufts, Sokoloff at the University of Oregon, and Laws at Dickinson College have conducted research studies to examine the error rate in fundamental acceleration concepts after acceleration has been taught by conventional methods and then after MBL experiments. In a study of 1200 students in calculus-based courses at five universities, after standard instruction the error rate was 70% on acceleration concepts. After completing two MBL labs with motion probes and dynamics carts, the error rate was reduced to 25% (Thornton, 1992, 1989).

Sokoloff in a study of students’ concepts of heat and temperature before and after MBL found that student error rate on heat and temperature questions after traditional

instruction ranged from 25% to 80%; after MBL experiments the range was less than 2% to 58% (Thornton, 1989).

Eylon and Linn (in press) reported that computer technology created an active learning environment in which middle school students could model experiments on displacement. After a series of scaffolded integrated activities with feedback and reflection loops, the students learned to predict and to compare results with the predictions. The students' understanding of thermal and displacement phenomena increased with computer use.

Layman and Krajcik (1992) reported that MBL technology can also help to change the misconceptions of teachers, but the process is a long one. Middle school teachers, in a MBL staff development project, were asked to respond to questions concerning heat and temperature concepts. Their responses were monitored over a two-year period in which they used heat and temperature probeware. Prior to the workshop, seven of the eleven teachers believed that temperature was a measure of heat energy. After the initial two-week workshop, eight of the eleven teachers held satisfactory views of heat, energy, and temperature. After using probeware for two years and participating in two summer workshops, all teachers had a good understanding of temperature. However, a few teachers never developed the concept of heat to the point of being able to describe what they would accept as suitable student answers to the distinction between heat and temperature. These teachers, with poor understandings of heat, were also unable to

suggest critical experiments that would help students develop a deep conceptual distinction between heat and temperature.

Clearly the role of the computer was important in the conceptual change of most of the teachers and their students. Even teachers who did not have a clear concept of heat developed a better concept of temperature through the use of the MBL. Layman and Krajcik (1992) concluded that professional development programs for teachers and technology should involve content knowledge as well as pedagogical knowledge. "It must, however, be recognized that this is such a new tool that we must all devote time and effort to bringing the microcomputer into an effective role in the life of the science teacher and the students in their classrooms" (p. 9).

Priscilla W. Laws, physics professor at Dickinson College, has been using computers to teach introductory physics for the past ten years. She has worked closely with Ron Thornton and David Sokoloff to develop curricula materials for teaching physics to both college and high school students. Four introductory physics curricula documents are available to teachers, *Workshop Physics II Activity Guide* (Laws, Boyle, Luetzelschwab, Sokoloff, & Thornton, 1994), *Real-Time Physics: Active Learning Laboratories* (Sokoloff, Laws, & Thornton, 1994/95), *Tools for Scientific Thinking Motion Laboratory Curriculum & Teachers' Guide* (Thornton & Sokoloff, 1994), and *Tools for Scientific Thinking Heat and Temperature Laboratory Curriculum & Teachers' Guide* (Thornton & Sokoloff, 1993).

Laws (Laws, Boyle, Luetzelschwab, Sokoloff, & Thornton, 1994) described her introductory physics course as activity-based with no formal lectures. Students participated in three two-hour sessions with one instructor and two teaching assistants. David Kolb's four-part learning sequence was followed in which students first examined their own preconceptions, then made qualitative observations, engaged in guided discussion and reflection with the instructor, and finally conducted quantitative experiments. The laboratory at Dickinson was recently redesigned to allow students to work in pairs at Macintosh computers and in groups of four at work stations. The majority of the class was spent in MBL experimentation and analysis. Spreadsheets and graphing programs were extensively used. In addition, students digitized information in a video format and used the computer to call up the information. Simulations were used sparingly. Students wrote lab reports that included data tables, graphs and apparatus drawings. Laws changed the way physics was taught at Dickinson and has influenced many high school physics teachers to change the way in which they teach physics. She has conducted summer institutes, written articles, made presentations, and published curriculum guides in print and disk formats.

Laws advocated using simulations sparingly; however, others have found that simulations complement and enhance learning (Hoffman, 1994; Krajcik & Berg, 1987; Ronen, Langley, & Ganiel, 1992; Trumper, 1994). Hoffman (1994) found promise in the use of simulations in conjunction with real-life experiences. Two programs, *Billiards* by Chuck Whitney of Harvard's Center for Astrophysics and *RelLab* by Paul Horwitz of

Bolt, Beranek, and Newman were two simulations he recommended for teaching introductory physics. These simulations allow students to relate the new concepts to what they already know. Hoffman said, "At their best, simulations enable students to reflect on the fundamental activity of science itself: creating models" (1994, p. 5).

Several people have reported on the use of *Interactive Physics™* (Hansson & Bug, 1995; Schwarz & Tavel, 1993; Roth, 1995). Simulation software used in conjunction with hands-on laboratories has been found to help students gain a "good understanding of the physical principles involved in the laboratory" (Hansson & Bug, 1995, p. 235). Roth (1995) found that *Interactive Physics™* simulations "(a) .. provide tools for the exploration of ideas; these tools take on meaning as part of teacher's (representatives of the physics community) situated practices. (b) Computer microworlds are settings for teachers to evaluate students' understandings about relevant phenomena by engaging them in conversations over and about the computer displays. (c) Computer microworlds are means to mediate the conversations between students and teacher so that both parties can make sense of the other's understanding" (pp. 344-345).

Schwartz (1989) discussed the use of the simulation software, *Geometric Supposer*, and said that we may be on the threshold of a new era in education if, "... we succeed in building environments in other domains that allow people to explore their own understanding, augment our notions of subject matter so that the making of new content is an endless process, [and] rethink ... the roles of students and teachers" (p.

61). Good computer software, he advocated, enables people to make conjectures and explore, to probe into their own minds by means of “intellectual mirrors.”

Assessment of the Effectiveness of Instructional Technology

A recent study at Harvard University (Woronov, 1994) reiterated that merely putting computers in classrooms will not reform education and ignite improvements in student achievement. Six myths associated with computers in the classroom were debunked. The first myth was that, “Computers are here to stay, so we have to get as many of them as possible into classrooms, as quickly as possible” (p. 1). The article quoted Martha Stone Wiske of the Educational Technology Center of Harvard, as she warned all stakeholders to “think carefully about why we want to use technology and what we hope to accomplish with it.” The article continued with dispelling the myths that teachers are technophobic, that programming computers teaches children to think and problem-solve, that wider use of technology will remedy inequalities and bring about systematic school reform, and that since kids love computers they must be learning. One of the promising practices identified was the use of computers in math and science in an active, inquiry-based, hands-on learning environment. Computer-based laboratories (MBL, sensors, probes) and simulations were identified as promising practices.

Roblyer (1988) reviewed the effectiveness of computer use in education from 1980 through 1987. He reviewed 38 studies and 44 dissertations in an attitude and achievement meta-analysis. He found that computer use was highly effective in the study of science. He further reported equal effects for males and females, lower and higher achievers, little

impact on attitude toward school work, and higher effects at the college level. Science simulations, he found, were more effective than any other application in increasing student achievement. All applications in mathematics were equally effective. The use of computers with English as a Second Language (ESL) students was found to be very ineffective as was the unstructured use of computer-assisted instruction (CAI).

J. D. and R. M. van Deusen (1989) called for educators to think about how computers can most effectively be used in instruction. They urged a reduction in the use of drill and practice software and an increase in the use of simulation, data collection, and management software. Database, spreadsheet and word processing software, they said were powerful tools for elementary and secondary students. They endorsed enabling student to “do science” by gathering and displaying data using computer-based laboratories.

The Link Between Technology and Restructuring

Following a conference sponsored by the Center for Technology in Education at Bank Street College in New York and the National Center on Education and the Economy in Rochester, five writers—Sheingold, Collins, Dede, David, and Kolderie—contributed papers on the link between technology and restructuring (Sheingold and Tucker, 1990). The conference looked at the difficulty and desirability of bringing together three areas of development in education—knowledge of how students learn and how to create educational environments that foster thinking and active learning; the potential of current and future interactive instructional technology; and restructuring and reform efforts.

Sheingold (1990), wrote, “Educators and policymakers nationwide now recognize the critical need for students to learn how to think, to understand concepts and ideas, to apply what they learn, and to be able to pose questions and solve problems” (p.13). Such goals that were only thought achievable by a small, select group of students are now mandatory in most of our nation’s schools. In order to achieve such goals, Sheingold suggested, environments will have to be created in which learners are actively engaged and teachers, as Cohen says, teach “adventurously.” Sheingold cited research (Brown, Collins, & Duguid, 1989; Chipman, Segal, & Glaser (Eds.), 1985; Resnick, 1987; Segal, Chipman, & Glaser, (Eds.), 1985) that described the classroom circumstances in which students develop deep understandings of academic content. Students should engage in complex authentic tasks such as conducting science experiments in which there is no “right” answer. Students should learn to work collaboratively and should be deeply engaged in subject matter learning. In order to accomplish these goals, the organizational structure of schools is being changed from forty-minute periods to more creative schedules in which projects can be worked on for longer blocks of time.

Technology has the potential to help organize and structure complex tasks through utility software such as word processors, databases, spreadsheets, and graphing programs. Networks can enable students to access and share information from many libraries and original sources. While technology has this capability, only a few teachers have been adventurous enough to integrate technology into their teaching practice (Sheingold & Hadley, 1990).

When districts have expanded their vision to include advanced technology, they have found that teachers “need more time to learn about, gain additional training in and plan for use of the technologies [sic]; want students to have longer blocks of time in which to do their technology based work; want to integrate curriculum [sic] and try team teaching; and need greater access to more technology for themselves and their students” (Sheingold, 1990, p. 17). These findings were supported by Becker (1993a, 1993b), Sheingold & Hadley (1990), and Dwyer, Ringstaff, & Sandholtz (1990a, 1990b). As Sheingold (1990) pointed out, these are the very things restructuring districts are seeking to change. “It is unlikely that widespread and effective use of technology to promote active learning can happen unless schools can reorganize their own structures, priorities and spaces” (p. 17).

Sheingold made the following recommendations to districts, “(1) Bring technology and learning to the same ‘table’ when restructuring is being planned. (2) Reconsider how technology is organized in the districts. (3) Work towards a critical mass of technology and teacher expertise [half of the teachers in the school] in using it. (4) Use media to convey new images and metaphors of schooling” (pp. 25-27).

Collins (1990) discussed the role of the computer in light of the two views of education, the didactic (teacher as information-giver and student as information-receiver) and the constructivist (teacher as facilitator and student as constructor of his/her own understandings). He identified eight major trends from literature and observation when computers are used as instructional tools. “(1) A shift from whole class to small group instruction. (2) A shift from lecture and recitation to coaching. (3) A shift from

working with better students to working with weaker students. (4) A shift toward more engaged students. (5) A shift from assessment based on test performance to assessment based on products, progress and effort. (6) A shift from a competitive to a cooperative social structure. (7) A shift from students all learning the same things to learning different things. (8) A shift from the primacy of verbal thinking to the integration of visual and verbal thinking” (pp. 32 - 35).

Collins said that districts should “put powerful, easy-to-use computers into place ...” (p. 43). Computers, he envisioned, are to be used as tools but perhaps more importantly as simulated environments, reflective environments, and video environments. As the nature of work changes to incorporate more computers, school work will also change to use computers in more constructivist and less didactic ways. “Using computers entails active learning, and this change in practice will eventually foster a change in society’s beliefs to a more constructivist view of education” (p. 44).

David (1990) viewed technology and restructuring as partners in change. Today’s schools, she said, need to be revamped from the inside out. The more powerful technology of today, unlike the past technology, offers powerful sources of information from the VCR, to the video disc player, to a multi-channel network. This new technology will change education as we know it when the technology is coupled with educational reform supported by educators, governors, businesses, parents, and school boards. The curriculum and instruction will change “from an emphasis on isolated facts, skills and

coverage to integrated content, applications of skills and conceptual understandings” (p. 75).

In order for change to occur in schools, David voiced the invitation to change must be made clear by flexible authorities who recognize that “restructuring requires new roles and responsibilities for everyone in the system....” (p. 78). She said, “Technology can act as a catalyst for change in several ways” (p. 79). An infusion of new technology gives us opportunity to rethink traditional practice. The very presence of the technology symbolizes change and can lead to changes in teaching and learning. She envisioned learners, “learning how to learn [with] no right answers”, teachers working as colleagues and decision makers, students involved in authentic problem-solving, and new roles and relationships in the classroom for teachers and students.

She warned however, “Even with considerable resources dedicated to teaching about technology, if other pieces necessary to support significant change are absent—knowledge about new ways to teach, and the flexibility to reorganize instruction, schedules, student groupings—only a few innovative teachers will change the way they teach as a result of the technology” (p. 84). Restructuring and the infusion of technology are difficult changes, and they must ultimately be supported by society if they are to have a long-term effect on the productivity of our schools.

Dede (1990) argued for a complete transformation of schooling and the use of advanced information systems. He envisioned learners using complex simulations designed to meet individualized needs. “During the next decade, advanced information technology

will increasingly amplify people's intelligence through cognitive partnerships between users and intelligent tools" (p. 66). The vital issue is not the number of machines in the classroom, "but how relationships between students and teachers and schooling and society will alter as a result" (p. 66).

Kolderie (1990) wrote that new technology has not had the same effect on education as it has on businesses and homes. The educational institution has been resistant to change even though there are real benefits to students and teachers. The urgency to improve schools and the impending turnover of the teacher corps in the next few years, "makes it imperative now to find an effective strategy for introducing new technology and new methods widely throughout the system" (p. 88).

Reason for Case Study Research in Physics Education

Prior research in the use of computer-related technology in physics education has been primarily quantitative in nature (Thornton, 1992, 1989; Hestenes, Wells, & Swackhamer, 1992). However, qualitative research methods allow the researcher to study the classroom phenomenon in more depth. Bromley (1986) wrote that case studies "get as close to the subject of interest as they possibly can, partly by means of direct observation in natural settings, partly by their access to subjective factors (thoughts, feelings, and desires) whereas experiments and surveys often use convenient derivative data, e.g. test results, official records. Also, case studies tend to spread the net for evidence widely, whereas experiments and surveys usually have a narrow focus" (p. 23).

Case studies are good for studying complex educational evaluation, because they are able to “explain the casual links in real-life interventions that are too complex for the survey of experimental strategies. A second application is to describe the real-life context in which an intervention has occurred. Third, an evaluation can benefit, again in a generative mode, from an illustrative case study—even a journalistic account—of the intervention itself. Finally, the case study strategy may be used to explore those situations in which the intervention being evaluated has no clean, single set of outcomes” (Yin, 1984, p. 25).

In summary, qualitative research is particularly suited for educational settings in which a complex phenomenon such as a classroom environment is studied. The novice researcher should be well-versed in qualitative techniques as described by experienced researchers such as Merriam, Yin, Strauss and Corbin, and Miles and Huberman. Care should be taken to collect data from multiple sources and to triangulate the data in order to report salient findings. The researcher should also be familiar with the phenomenon and setting of the study.

CHAPTER 3

METHOD

A case study of an exemplary technology-using physics teacher was conducted. The anonymity of the teacher, the school district, and all participants was maintained. Any names used in this study are fictional.

The case study approach was chosen since the phenomenon under study, the behaviors of students and teachers in a computer-using classroom environment, was not distinguishable from its context, the greater school environment, central county-support systems, and other extraneous influences. Furthermore, the variables in this study were complex and could not be manipulated. Cline (1994b) said that qualitative research methods are appropriate when “issues for which the independent and dependent variables cannot be specified, the processes of interest cannot be specified, and no manipulation of the conditions of the study can be carried out” (p. 1).

The research data were triangulated by collecting data from various sources: video tape recordings of the classroom teacher and individual groups of students, audio tape recordings of conversations and structured interviews, scripted observations, teacher lesson plans and grade books, student responses on the *Force Concept Inventory*, and student work products including lab reports and HyperCard stacks.

These audio tapes, video tapes, and printed classroom materials provided data sources, recorded events and documented interactions between the teacher, the students,

and the technology in the classroom. Demographic data were collected from interviews and from the Office of Management Information Systems. Documents such as school enrollment reports and technology plans were examined. The structured interviews included administrators at the school, the district central office, teachers in the school, and teachers outside the school. Yin (1993, p. 32) emphasized the importance of having multiple sources of evidence converging on the same set of issues. He explained that “the most robust fact may be considered to have been established if three (or more) sources all coincide.” Yin suggested that in successful triangulation, the same question asked of different sources of evidence all yield the same answer.

Case Study Research

Merriam (1988) wrote, “The case study offers a means of investigating complex social units consisting of multiple variables of potential importance in understanding the phenomenon. Anchored in real-life situations, the case study results in a rich and holistic account of a phenomenon. It offers insights and illuminates meanings that expand its readers’ experiences. These insights can be construed as tentative hypotheses that help structure future research; hence, case study plays an important role in advancing a field’s knowledge. Because of its strengths, case study is a particularly appealing design for applied fields of study such as education” (p. 32).

“Case study research continues to be an essential form of social science inquiry. The method is appropriate when investigators desire to: (a) define topics broadly and not narrowly, (b) cover contextual conditions and not just the phenomenon of study, and (c)

rely on multiple and not singular sources of evidence” (Yin, 1993, p. xi). Furthermore Yin (1993) said, “The major rationale for using this method is when your investigation must cover both a particular phenomenon and the context within which the phenomenon is occurring, either because: (a) the context is hypothesized to contain important explanatory variables about the phenomena, or (b) the boundaries between phenomenon and context are not clearly evident” (p. 31) . The student-teacher interactions in the physics classroom cannot be taken out of context of the greater school environment; the neighborhood; district plans, curriculum, and support groups; and outside computer support groups.

Inductive research, known as grounded theory, has been described by Strauss and Corbin (1990) as “One that is inductively derived from the study of the phenomenon it represents. That is, it is discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon. Therefore, data collection, analysis, and theory stand in reciprocal relationship with each other. One does not begin with a theory, then prove it. Rather, one begins with an area of study and what is relevant to that area is allowed to emerge” (p. 23).

Yin (1993) emphasized the importance of having multiple sources of evidence converging on the same set of issues. He explained that “The most robust fact may be considered to have been established if three (or more) sources all coincide” (p. 32). Yin suggested that in successful triangulation, the same question asked of different sources of evidence all yield the same answer.

Merriam (1988) quoted Denzin on various ways to triangulate. The kinds of triangulation are by data source (persons, times, places), by method (observation, interview, documents), by researcher, and by theory. Miles and Huberman (1994) added data type (qualitative text, recordings, quantitative).

Miles and Huberman asked what can we expect from triangulation. Mathison (as cited in Miles & Huberman, 1994) answered convergence, inconsistency, and contradiction. Convergence occurs when data from different sources or collected by different methods lead to the same outcome; i.e., converge. Convergence is the goal of triangulation (Yin, 1993; Miles and Huberman, 1994; Mathison, 1988). Sometimes data from different sources are inconsistent and may even conflict. Inconsistent data do not confirm but lead the researcher to construct plausible explanations. Conflicting data lead the researcher to dissimilar conclusions. In the case of inconsistent and conflicting data, the researcher must look to the broader context to help to clarify and create meaning. Triangulation becomes, as Miles and Huberman expressed, not so much a tactic but “a way of life.” The verification process is built into the data collection as you collect data from various sources and double-check findings, using multiple methods of data analysis.

Miles and Huberman (1994, p. 2) reminded the qualitative researcher that there are “pervasive issues” such as labor-intensiveness of data collection, frequent data overload, researcher bias, time demands of processing coding data, the adequacy of sampling, generalizability of findings, the credibility and quality of conclusions and their utility in

policy actions. The traditional quantitative terms of reliability, validity, and generalizability are addressed differently in qualitative research.

Miles and Huberman (1994) cited the earlier work of Miles (1979) in discussing a lingering question in qualitative research, “The most serious and central difficulty in the use of qualitative data is that methods of analysis are not well formulated. For quantitative data, there are clear conventions the researcher can use. But the analyst faced with a bank of qualitative data has very few guidelines for protection against self-delusion, let alone the presentation of unreliable or invalid conclusions to scientific or policy-making audiences. How can we be sure that an ‘earthy,’ ‘undeniable,’ ‘serendipitous’ finding is not, in fact, *wrong*” (p. 2)?

Since 1979, many researchers have advanced the methodology of qualitative research. Traditional canons of quantitative research have to be “retained and redefined” as Strauss and Corbin (1990) expressed. “These canons of significance, theory-observation compatibility, generalizability, consistency, reproducibility, precision, and verification have been defined in their procedures of grounded theory research” (p. 250). They describe grounded theory methods of conducting qualitative research that includes specific designs and methods of analysis.

The methods of qualitative research have begun to be explicated by other practitioners as well. Miles and Huberman (1994) outlined some common features of analytic methods.

- Affixing codes to a set of field notes drawn from observations or interviews

- Noting reflections or other remarks in the margins
- Sorting and sifting through these materials to identify similar phrases, relationships between variables, patterns, themes, distinct differences between subgroups, and common sequences
- Isolating these patterns and processes, commonalities and differences, and taking them out to the field in the next wave of data collection
- Gradually elaborating a small set of generalizations that cover the consistencies discerned in the database
- Confronting those generalizations with a formalized body of knowledge in the form of constructs or theories (p. 9)

In the analytical process of what Strauss and Corbin called open coding data and what Miles and Huberman called data reduction, data are summarized, coded, categorized, clustered, and referred to in memos. Memos are written as historical records of the research process to assist the researcher in remembering the thought process she has gone through, questions asked, the ways of thinking and analyzing data, and the next steps to be taken in the field.

Strauss and Corbin (1990) wrote about various ways to validate findings. They suggested using literature, “When you have finished developing your theory and are writing up your findings, you can reference the literature in appropriate places to give validation of the accuracy of your findings” (p. 52). In addition, as one examines nontechnical literature—letters, diaries, reports, videotapes, newspapers—it is important

to cross-check these against other sources of data such as interviews and observations, if possible.

Miles and Huberman (1994) suggested that conclusions are verified in the process of analysis. “Verification may be as brief as a fleeting second thought crossing the analyst’s mind during writing, with a short excursion back to the field notes, or it may be thorough and elaborate, with lengthy argumentation and review among colleagues to develop ‘intersubjective consensus,’ or with extensive efforts to replicate a finding in another data set. The meanings emerging from the data have to be tested for their plausibility, their sturdiness, their ‘confirmability’—that is their validity”(p. 11).

In qualitative research, reliability and validity are inseparably linked. Guba and Lincoln (1981) wrote of this connection, “Since it is impossible to have internal validity without reliability, a demonstration of internal validity amounts to a simultaneous demonstration of reliability” (p. 120).

Reliability refers to the extent to which findings can be replicated or reproduced. As Merriam (1988) wrote, “Reliability in a research design is based on the assumption that there is a single reality which if studied repeatedly will give the same results” (p. 170). Corbin and Strauss (1990) pointed out that “Probably no theory that deals with a social/psychological phenomenon is actually reproducible, insofar as finding new situations or other situations whose conditions exactly match those of the original study, though many major conditions may be similar” (p. 250). They recommended that reproducibility be redefined as follows, “Given the same theoretical perspective of the original researcher

and following the same general rules for data gathering and analysis, plus a similar set of conditions, another investigator should be able to come up with the same theoretical explanation about the given phenomenon” (p.251). Achieving reliability in the traditional sense is really impossible since the object of study is complex, highly contextual, and multifaceted.

The skills of the researcher, to a great extent, determine the reliability and validity of the study. Miles and Huberman (1994) have suggested some “markers of a good qualitative researcher-as-instrument.” They are:

- some familiarity with the phenomenon and the setting under study
- strong conceptual interests
- a multidisciplinary approach, as opposed to a narrow grounding or focus in a single discipline
- good “investigative” skills, including doggedness, the ability to draw people out, and the ability to ward off premature closure (p. 38)

Verification is also a part of the process of axial coding, or putting data back together in new ways by making connections between categories. These steps outlined by Strauss and Corbin (1990) are: “(a) the hypothetical relating of subcategories to a category by means of statements denoting the nature of the relationships between them and the phenomenon—causal conditions, context, intervening conditions, action/interaction strategies, consequences; (b) the verification of those hypotheses against actual data; (c) the continued search for the properties of categories and subcategories,

and the dimensional locations of data (events, happenings, etc.) indicative of them; (d) the beginning exploration of variation in phenomena, by comparing each category and its subcategories for different patterns discovered by comparing dimensional locations of instances of data” (p. 107). Questions are formed in this process and asked of the data. If the questions are supported, then statements of relationship can be made. This is a method of verifying and validating the conclusions.

In qualitative research it is also important to be looking for cases in which our statements are not verified. As Strauss and Corbin (1990) suggested, there are instances where our statements do not hold up. “They don’t necessarily negate our questions or statements, or disprove them, rather they add variation and depth of understanding” (p.109). They called this adding “density and variation” to the theory that is being developed.

Data were analyzed following methods outlined by Miles and Huberman (1994) and Strauss and Corbin (1990). In the analytical process of what Corbin and Strauss labeled “open coding” data and what Miles and Huberman called “data reduction,” data were summarized, coded, categorized, clustered, and referred to in memos. Memos became written historical records of the research process to assist the researcher in remembering the thought process she went through, questions asked, the ways of thinking and analyzing data, and the steps that were taken in the field.

Validity, reliability, and generalizability—the canons in quantitative experimental research—are defined differently in qualitative research. The study will not be generalized

beyond the teacher and classroom studied since no two situations are exactly the same. In quantitative research, one samples a population to be representative of the entire population so that generalizations to the population can be made based on the sample. Representativeness is a major concern of the quantitative researcher and he uses randomization and statistical measures to minimize errors. In grounded theory qualitative research, “Our concern is with representativeness of concepts in their varying forms” (Corbin and Strauss, 1990, p. 190). They further wrote, “ ... we are not attempting to generalize as such but to specify. We specify the conditions under which our phenomena exist, the action/interaction that pertains to them, and the associated outcomes or consequences” (p. 191). Therefore, “It is generalizable to those specific situations only” (p. 251). The researcher sought to specify the conditions under which the phenomenon existed and sought to obtain sufficient data to be representative of the concepts.

Cline (1994a) wrote, “Generalization of data is never done. Generalization of theory is always done” (p. 3). Samples in qualitative research are not randomly selected; therefore, the results cannot be expanded to a general population. “If you have fully described the object of interest and understand how it operates in its context, then any theory you develop can be generalized to comparable ... situations” (p.3). A comparable situation exists if the processes are operational even though the specific details differ.

Validity and reliability are to some extent, as Miles and Huberman suggested, dependent on the researcher. The researcher in this study is familiar with the phenomenon and the setting under study. She is a former teacher of chemistry, mathematics, and

physics and has used computer-related technology in the classroom. She is currently the district high school science instructional specialist and supports the planning, writing, and implementation of the high school science curriculum and the county technology plan for high school science.

Literature was used prior to the study to define the research in teachers and technology, and then later, after the data were collected and findings were being developed, literature was used to validate findings as Corbin and Strauss (1990) suggested. “When you have finished developing your theory and are writing up your findings, you can reference the literature in appropriate places to give validation of the accuracy of your findings” (p. 52).

Acquiring Knowledge of Student Understanding and Learning

The major thrust of this study was to observe the process by which the technical resources of the physics lab/classroom were used by the instructor to guide learning. In order for this process to occur, it was clearly necessary that the instructor understand and assess the physics conceptual understandings that students develop over time. In the normal course of the instructional process, the instructor regularly observes, queries, teaches, and assesses in order to acquire this information. These were the sources of information that were used in the present study as well. In fact, the widest range of sources possible provided the richest data set about student understanding and the researcher added observations of her own about student understandings.

This research focused on the interactions of the teacher, the students, and the technology as the teacher guided the instruction based on his dynamic assessment of student understandings. This interaction took place in the context of a classroom which utilized computers, CD-ROMs, videodisc, and videotape technology along with traditional physics apparatus. Thus, it afforded this researcher the opportunity to observe and record the potential for teaching and learning influenced by the technology.

In order to develop the appropriate data set, and to track the information available to the instructor, the following sources of data were utilized.

- sample laboratory reports or sample answers to questions concerning laboratory activities
- tests, quizzes, and problem sets
- HyperCard stacks created as an assessment
- audiotape and videotape transcripts of student and teacher conversations
- audiotape recordings of interviews of 4 teachers and 1 assistant principal
- *Mechanical Universe High School Adaptation* quiz handouts
- post-test student responses on the *Force Concept Inventory*
- final exams in both Physics 1 and Physics 1 GT
- the teacher's gradebook and lesson plans
- the researcher's logbook of daily events

These data were used to verify that the students had gained or had not gained an understanding of introductory physics. The reader should note that the specific purpose in

collecting the data outlined above was not to determine changes in students which can be attributed to the utilization of this new technology. An attribution study of that sort requires large numbers of students, random assignment of students to experimental conditions, and highly reliable/valid measurement. Carefully controlled experimental conditions of this sort must be used in order to carry out a causal attribution study. However, the goal of this study was quite different, despite the fact that an assessment of student understandings was also necessary in this study. The role of student assessments in this study was to provide an opportunity to observe the interaction between instructor and students, whereas the role of student assessment in a causal study is to assess the nature and amount of learning attributable to specific independent variables. These are quite different roles and cannot exist simultaneously in the same study. This study utilized a few students observed over a long period of time as they interacted with the technology, the instructor, and their fellow students. In traditional research terms, this study is designed as a process or formative study rather than a summative or outcome study. However, information about student learning was collected (for the specific purposes described above) and was then used to speculate about how the technology facilitates, or does not facilitate, the acquisition of knowledge of physics.

Why an N of One?

Cline (1994a) said, “A full and complete description of a single site (case) will contain all that is necessary for the generation of a useful set of hypotheses” (p. 2). A human event theoretically can be studied with an n equal to one. The idea is to study in-

depth and to study those events which persist over time. Cline continued (1994b), “Focus on one object (case) at a time and do not go to another case until the first is analyzed. Subsequent cases should always be selected purposively” (p. 2).

Yin (1984), discussed the rationale for single-case designs. He said, “The single-case study is an appropriate design under several circumstances” (p. 47). A single case can represent the critical case of a significant theory. Yin talked about Neal Gross et al. and the single school focus of their book, *Implementing Organizational Innovations* (1971). In the Neal case, a single school was selected because of its history of innovation and lack of barriers to innovation. The failure of the innovation in the study was due to the implementation process and thus changed the focus of subsequent research to studies of the implementation process.

In addition, single cases can be so unique that the single case is worth documenting, and the single case may be revelatory. This situation exists when an investigator has an opportunity to observe and analyze a phenomenon previously inaccessible to scientific investigation.

The time required and the financial burden of audio taping and video taping multiple teachers was also a consideration. From preliminary studies, the researcher determined that in order to capture and analyze the interactions of teachers, students, and technology, several continuous days of video taping were needed. The progress students make over the course of the year was also important. In short, an in-depth study of one teacher and his students was thought to be critical to the questions asked in the study.

In preliminary studies, the researcher observed ten teachers in six schools, scripted the observations of seven teachers in three schools, and videotaped four teachers in two schools. Analysis of the videotapes illustrated that many of the same actions were present in the classes of experienced teachers who were at the same level of development. The analysis of the class visits is in Appendix A.

Why This Teacher?

The teacher in the study is an experienced physics teacher who was one of the original pilot teachers in a 1991 district effort to use Macintosh and IBM computers in physics. He taught earth science for five years and then physics for an additional seven years prior to the study. As a pilot teacher, the teacher was provided with a series of staff development opportunities through Apple Computer and the school district beginning in the Spring of 1991. He participated in Apple-Talk Network Training at Clinton Computer, Stella Training, Macintosh Fundamentals, Probeware Training, HyperCard Training, and Peripheral Use Training. In addition, he participated in staff development on how to become a skillful teacher and in a *Mechanical Universe High School Adaptation* Workshop for Physics Teachers. He has also served as a teacher of teachers. He co-taught the Physics Teachers Computer Training and Curriculum Development Workshop, a forty-hour staff development for all physics teachers that was part of the implementation of physics computer labs in the district's twenty-plus high schools. He has taught non-college credit courses in ClarisWorks Word Processor, Database and Spreadsheet, HyperCard for Teachers, and Macintosh Fundamentals. He is an Apple Consultant in

Education and has worked in Chesterfield and Gloucester Counties, VA, and in Phenoxville, PA. He has presented at national conferences including the American Association of Physics Teachers and the National Science Teachers Association.

In preliminary studies, the researcher observed his classes and has found evidence of advanced computer use with students. He is on stage 6 of refocusing in the stages of concern and is at or beyond the appropriation stage on ACOT's Instructional Evolution.

Why This School?

Students attending this high school are heterogeneously mixed and come from diverse economic and ethnic backgrounds. Physics enrollment has been increasing although the overall student population has been decreasing over the last three years. Administrative support for risk-takers is evident and the teachers have positive things to say about the school climate. This high school offers the best opportunity to explore computer use in the most topics or units of study in physics in the shortest amount of time. The high school in the study was on a semester-semester schedule and began classes on February 1, which was conducive to a long-term study. All classes meet for 90 minutes every day and students who successfully complete the semester receive a credit in physics.

Research Plan

Interviews were conducted with the teacher of the study, other appropriate teachers in the science department and school, and the assistant principal. Permission was granted by all participants for the interviews to be audio taped. (See a copy of the consent forms used in this study in Appendix B and see Appendix C for a copy of questions that

guided interviews.) The researcher made audiotapes and videotapes of classes at selected times during the semester. In preliminary studies, the researcher found that it is important to return to the classroom on consecutive days to capture extended laboratory experiments from the initiation to the completion of the laboratory report. Therefore, classes were observed on consecutive days as appropriate to record a unit of study.

In addition to making audiotapes and videotapes, written notes about the events of the day or other ideas and thoughts were recorded by the researcher in a bound logbook. These notes were transcribed and imported into *Ethnograph*. Teacher lesson plans, handouts, and other documents were collected throughout the semester. Samples of student HyperCard stacks and other forms of alternative assessment were collected. In addition, the Office of Management Information Systems' data were examined for grade distribution and membership.

Classroom Data Collection Technique

During each class observation, the researcher recorded in a logbook classroom conditions, equipment, handouts used during the class period, class activities, and weekly schedules posted on the whiteboard. Seventeen days (fifty-one hours of instruction time) were video taped. All classes were video taped with two cameras, a VHS stationary camera on a tripod at the rear of the room, and a VHS-C camera hand-held by the researcher. In addition, two Radio Shack Realistic PZM® microphones and two General Electric microcassette recorders recorded conversations of two different student groups.

A microphone and a microcassette recorder were also used for the teacher and principal interviews.

The teacher used a lapel remote microphone to record onto the sound track of the stationary camera's videotape. The sound track from the stationary camera usually began before the ninety minute class started and ended with the closing bell to mark the end of the period. The hand-held camera was used after the groups of students began a laboratory experiment, a simulation, a collaborative quiz, or another class activity. The researcher and the teacher pre-selected the group to be taped depending on the activity and the physical space in the classroom. Groups of only girls, only boys, and mixed gender groups were taped over the course of the observations.

The main body of raw data were the 66 videotapes—34 VHS and 32 VHS-C— from the classroom. Two 90-minute classes, Physics 1 and Physics 1 Gifted and Talented (GT), were observed for seventeen days over a three-month period. In addition, there were 7 audio tapes made during the interviews with a principal and 4 teachers and 56 audio tapes made of student groups.

Data Analysis Process

All videotapes were viewed several times, audio tapes were listened to, and notes were made on which tapes offered usable information about the use of instructional technology. Selected videotapes were transcribed from the initial days of the observation, April 3; the middle days, April 26; and the final days, June 2. Some of the audiotapes from those dates were partially transcribed; others were completely transcribed. They were used

to verify the words transcribed from the sound track of the videotapes. The April 3 and April 28 tapes offered the most diverse use of computer, videotape, and videodisc technology. Class activities during the week of June 2 revolved around the use of traditional physics apparatus to study electricity and magnetism and the computer was used only for word processing laboratory reports. Additional tapes were then reviewed once again and some were transcribed around the April 3 and April 28 dates. April 3, April 4, April 26, and April 28 audiotapes and videotapes contained interesting student conversations and were analyzed in detail.

Once the information was collected, the process of transcribing selected videotapes began. Each 90-minute stationary camera videotape took 40 hours to transcribe, code, and recode. Labeling events, actions, and processes began in what Corbin and Strauss called “Open Coding” as described in Chapter 2. The Open Coding process was critical since those events, actions, interactions, and conversations which the researcher found salient were identified and labeled. The data were then extracted from the volumes of information collected. The information—field notes, audiotapes, the interpretation of actions and the sound tracks of videotapes, documents—was coded by transcribing it into *WordPerfect 5.1*. The word processed documents were saved as a text files without breaks and imported into *Ethnograph v4.0* for coding. *Ethnograph v4.0* numbered each line of the document and the document was printed and analyzed. The copy was marked by hand and code words were attached to words, lines, or paragraphs as deemed salient or appropriate. The code words were entered into *Ethnograph v4.0* and the coded versions of the

documents were printed. As the code words began to emerge, code words that were different but labeled similar events were often recoded to the same word to have consistency in labeling these events. A running code word dictionary with definitions was very helpful. (See Appendix D for a sample dictionary.)

Code words came from the researcher's experience in observing and writing formal reports in the school district's Teacher Performance Evaluation Program based on Saphier's *Skillful Teacher* (1987) as well as the researcher's years of experience as a classroom teacher and as a science curriculum specialist. The researcher used code words to describe actions, events, and products (documents) as completely as possible. There was always a possibility of error or bias in selecting the salient events and the code words used to describe events and processes. In the coding process, transcribed notes were frequently shared with two to four other people who gave the researcher feedback on the coding of passages. Every attempt was made to keep an open mind and to question the information and data to describe "what was happening." A list of the code words used, the symbols, and operational descriptions of the words was produced.

The code words were then categorized according to parent words which linked data together. The code words, parent code words, and definitions were printed and analyzed.

The process of coding was a dynamic one. As more and more data were coded and the process of identifying code words was refined, the earlier coded data were re-examined and recoded. A constant process of contrast and comparison was done, the

major themes were identified, and the data were reexamined to look for further evidence of these major themes. Hypotheses about the data were developed and tested in this re-examination process. The final step in the analysis was the explanatory process.

Four examples of student dialogs were chosen to tell the story of the technology-rich classroom. The criteria for selection of these conversations were relatively simple—they had to illustrate clearly how students and the teacher interacted when instructional technology was an integral part of the learning process. The dialogs had to be representative of computer use in physics—simulations, lab probeware experiments, graphing, word processing. The students in the dialog had to come from regular physics classes as well as honors classes. The audiotapes and videotapes had to be of good quality so that actions and words could be transcribed with certainty.

In the process of reporting the findings, the conversations were analyzed for the reader to better understand what was occurring in the classroom. The analyses were followed by discussions of the physics concepts and the pedagogy that were evident. Conclusions were drawn. The research questions that were posed were answered.

In addition to the qualitative research process, a quantitative piece was added as the researcher analyzed student responses to the *Force Concept Inventory*. Students in the study were compared to students in the Hestenes, Wells, and Swackhamer study (1992).

CHAPTER 4

FINDINGS

At the onset of this research study, the researcher believed that instructional technology such as computers, probeware, videodiscs, and videotapes contributed to student learning. However, she did not know how students learned physics with the computer and video technology, nor did she know how teachers had adapted the use of instructional technology in their teaching practice. The researcher did not know if she would find evidence of learning or not.

Student understanding of physics concepts was examined by several methods—analysis of audio and video transcriptions of student-student and student-teacher conversations during physics class; analysis of student products including laboratory reports, tests, quizzes, HyperCard productions, and homework assignments; interpretation of observations and notes made during the classroom visits; interviews with teachers, and analysis of student results on the *Force Concept Inventory* (FCI) developed by Hestenes, Wells, and Swackhamer (1992). A presentation of the qualitative findings will be followed by the analysis of the inventory. Due to the reasons discussed in the analysis of the *Force Concept Inventory*, the results of the inventory can not be relied on as a measure of the students' conceptual understanding of forces.

The following questions guided this research:

1. What is the daily teaching practice of an experienced computer-using high school physics teacher?
2. What are this teacher's expectations of students and instructional technology?
3. What are the physics classroom processes and interactions when computers are used to teach high school students?
4. What barriers and support mechanisms affect the use of technology in this physics classroom?
5. How do the students, the teacher, and the technology interact in the learning environment?
6. What is the unique contribution of computer-related technology to student-teacher and student-student interactions? Are there cognitive representations of computer output that make interaction different from traditional lecture and laboratory methods?
7. How do the interactions between the teacher, the students, and the technology affect student conceptual understanding?

Analysis of Qualitative Research

The qualitative research focused on the student and the classroom environment in an effort to provide good illustrations of computer use. The researcher wanted concrete evidence of student use of computer-related laboratories in the process of learning physics. Evidence was provided through student conversations and actions in the classroom. In addition to studying the conversations between students, the role of the teacher and the conversations between the teacher and individuals or groups of students were also studied.

The teacher's role in this technology-rich environment has changed from the traditional role of information-giver. He not only has to know and to be able to transfer content knowledge in his subject area; he must understand pedagogy, and be able to competently use the new technology with his students. The technology changed the experiences that students have in the physics classroom and changed the activities and dialogs of the teacher and the students.

The Hardware, Software, and Other Resources

The teacher planned activities using multiple resources (see Appendix E for a complete listing of the software and other resources). During the school year he planned and conducted over twenty extensive activities using the probeware for experiments. He used twelve simulations during the school year including commercially produced materials from *Interactive Physics II™*, *Interactive Physics II™ Simulations* by Addison-Wesley, and six of the simulation software packages from the *Physics Explorer Series* by Logal Educational Software—*Gravity*, *Waves*, *Ripple Tank*, *Diffraction*, *Harmonic Motion*, and *AC/DC Circuits*. Students used the *Interactive Physics II™* software package to create their own simulations in the study of conservation of momentum and energy. The teacher used twelve *Mechanical Universe High School Adaptation* videotapes to illustrate physics concepts. He used multiple segments of still frames and short movie clips from the videodiscs *Physics of Sports*, *Cinema Classics*, and *The Tacoma Narrows Bridge* to illustrate physics concepts. Students benefited from the teacher's planning and use of

multiple resources because their different learning styles were addressed and students were active participants in the learning activities planned by the teacher.

The teacher and students used probes or probeware to perform computer-based experiments. Probeware is a combination of sensors and software. The sensors measure physical phenomena such as time, distance, or force, and the software converts the information to visual displays in the form of data tables and graphs. The students used many probes during the course of the year including motion detectors, photogates, Smart Pulley, force sensors, light sensors, and magnetic field sensors. All of these sensors or probes were connected to the computer through a device known as the Universal Laboratory Interface. These devices and how they work will be more clearly defined in the two examples of probeware—*Smart Pulley Lab on Impulse, Momentum, Work, and Energy* and *Impulse and Momentum Lab*.

The hardware in the classroom during this study (see Table 1) had been in place for two to three years. Five of the student computers were Macintosh LC models and five were Macintosh LC IIIs. Because the computers had only 4 megabytes of random access memory (RAM), students had to restart the machines when a program crashed several times during the observation. Lack of RAM was one of the barriers to the use of the technology that was discovered during the study. Most physics educational software currently available requires 8 to 16 megabytes of RAM.

In addition to student stations, the teacher had a more powerful machine, a Macintosh Centris 610, attached to an overhead projection device for whole class

presentation. A VCR and a videodisc player were connected to a 27-inch monitor at the front of the room. The monitor also served as a computer monitor for sight impaired students.

Table 1

Hardware Used in Physics Classes During Study

Hardware	Description of Use
Macintosh Student Stations (5 LCs & 5 LCIIIs, 4/80)	10 computers networked for student use, one computer for every two to three students in the class
Macintosh Teacher Station (1 Centris 610, 8/80)	Teacher computer with extra memory used for personal word processing, grade keeping, and introduction of software
Laser Printer	Printer connected by Apple Talk network to all computers for print sharing
Overhead Projection Device	Black/white visual display of the teacher computer screen used in conjunction with an overhead projector for whole class instruction
Videotape Player	A videotape player connected to a large screen monitor/TV used for <i>Mechanical Universe High School Adaptation</i> videotapes
Videodisc Player	A videodisc player connected to a large screen monitor/TV used for visual illustrations of physics concepts
27-inch Monitor	Large screen monitor used for computer display for whole classes or individual students; monitor connected to computer, VCR, and videodisc player

There were many pieces of software used by the students during the year. (See Table 2 for a list of the software used during the study and Appendix E for a complete list of the software and other resources used by the physics classes during the year.)

The teacher managed instruction and established a learning environment in which students could easily access the technology. He loaded software programs onto the hard drives of each computer and then organized the applications into computerized “folders.” The students quickly learned the programs and how to access them. They learned features of the Macintosh such as opening folders, reading through the menus, and using the Find feature of the machine. Each program has similar features such as File, Edit, Window, and Font making it easier for students to problem-solve by using the pull-down menus associated with the software.

Examples from the Technology-Rich Classroom

The researcher will now provide the reader with evidence of the importance of computer technology with four examples from the classroom. The following dialogs occurred in four different class periods; three of the examples were from the regular physics class and one example was from the physics gifted and talented (GT) class. These examples were taken from two different units of study, one from circular motion, and three from an extended study on the conservation of momentum and energy. Both of the units are important for student understandings of physics as defined in the National Science Education Standards (National Research Council, 1996). Two of the examples illustrate the use of simulations and two examples illustrate the use of probeware.

Table 2

Software Used in Physics 1 and Physics 1 GT Classes During the Study

Software Title	Publisher	Description
ULI Timer	Vernier Software	Software that graphs or displays data in table form for timing devices such as the Smart Pulley and photogates
Physics Explorer: Gravity	Logal Educational Software	Programs that simulate the motion of a body in a gravitational field of a massive fixed body
Interactive Physics II™	Knowledge Revolution	Interactive simulation software that allows students to create simulations of physical phenomena, change variables and collect data
Interactive Physics II™ Simulations	Addison-Wesley	32 simulations and printed instructional materials that aids in the study of physics concepts
At Ease	Claris	A computer management software that enables the teacher to control student access to the computer control panel and applications
ClarisWorks for Macintosh	Claris	Integrated utility package of word processor, database, spreadsheet, drawing, paint, presentation, and communication software that was used by all students
CA Cricket Graph III	Computer Associates	Graphing and statistical analysis software used by all students for special research projects

Although many groups were taped during the three-month study, the four examples contained within this document have more girls than boys. Both classes were composed of approximately 57% girls and 43% boys. Two examples were from girls-only teams and two examples were from boy-girl groups. The tape transcriptions of the mixed teams or the girls-only teams happened to be better examples of computer use. There were a couple of boys-only teams observed during the research; but the lack of appropriate class activity, physical location within the classroom, or lack of dialog resulted in the non-use these tapes. One team of two boys always worked at the back of the room in an area too narrow for good tapes to be made of student activity. One boys-only group that was taped had little transcribable dialog. The teacher and the researcher discussed the groups to be taped during each classroom observation.

In the first example, *Physics Explorer Simulation Activity on Circular Orbits*, the Physics 1 class was about half-way through their study of circular motion. They had completed the study of kinematics, Newton's laws, and simple harmonic motion. The girls in the illustration had just begun a new simulation, *Physics Explorer: How 'Heavy' Is a Planet?*

Three examples were taken from the analyses of the April 26 and April 28 videotapes and audiotapes of both regular and GT physics classes. These conservation of momentum activities were part of a three-week (27 hours of instruction) unit on conservation laws during which students completed three laboratory experiments using probeware, read and worked three homework problem sets from the Hickman's *Problem-*

Exercises in Physics and Hewitt's *Conceptual Physics*, created a simulation using *Interactive Physics II™*, completed two other simulations—*Rocket Sled I* and *Rocket Sled II*, and viewed and were quizzed on two Mechanical Universe High School Adaptation videotapes—*Conservation of Energy* and *Conservation of Momentum*. Two of the examples were from probeware experiments and one was from the *Rocket Sled I* simulation activity.

Example of Physics Explorer Simulation, Study of Orbital Motion

Physics Explorer is a series of computer-based simulations from Logal Educational Software that enables students to model experiments, interactively record results of experiments to spreadsheets, and generate graphs. The software allows high school and college introductory physics students to experiment in a simulated environment in which variables can be changed or controlled in programmed or independent designs. In each program there are several windows—meters or variables windows, spreadsheet window, model window, graph window—which can be displayed on the computer screen as well as icons that perform operations such as Run, Stop, Record, and Reset. Figure 1 illustrates what the students see on their computer screens.

In the meters or input variables windows, students input data such as height, velocity, or mass. In this particular simulation, students enter the height and the corresponding speed that they calculate based on the orbital radius of the satellite around Earth. The action or model window illustrates the effect of changing these variables on the path of the satellite. If students choose to activate the Trace feature of the software, the

path of the satellite is illustrated by a dotted pattern. The graph window generates a graphical representation of the action in real-time. The icons in the program were chosen to represent action that makes sense to students; for example, the icon to run the program is a picture of a human figure running and the icon to stop the program is an open hand on a stop sign.

Physics Explorer: Gravity contains three core concept investigations, *Circular Orbits*, *Kepler's Second Law*, and *How "Heavy" Is a Planet?* Each of the programs

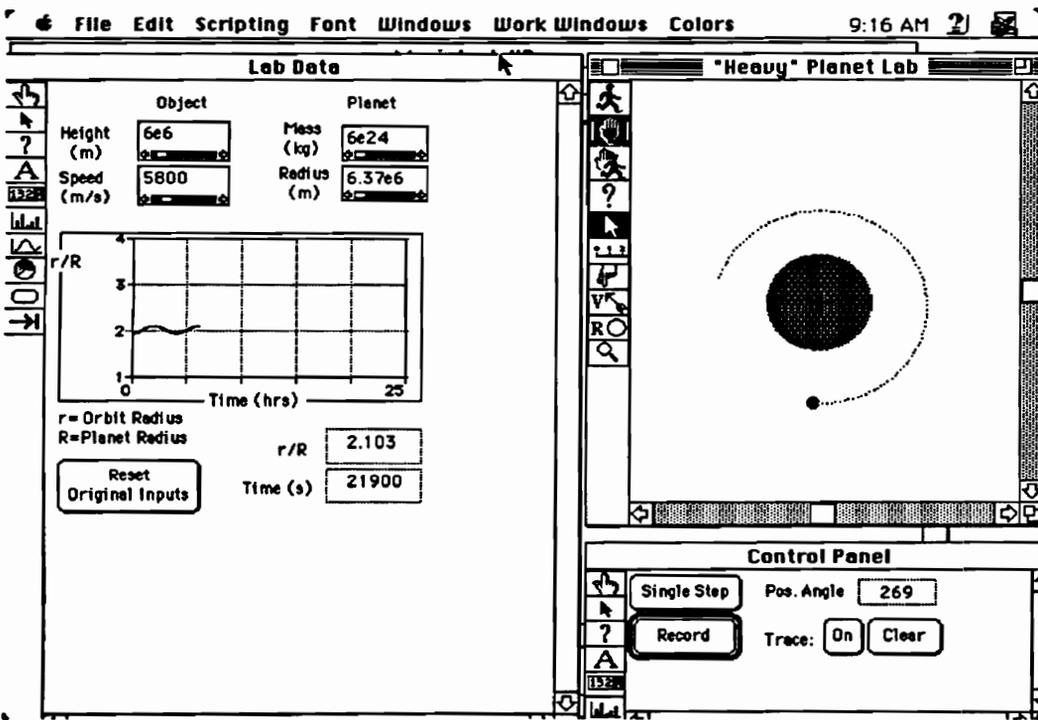


Figure 1. Meters or variable input windows, graph window, and model window of *Physics Explorer:*

Gravity, *How "Heavy" Is a Planet* screen. *Physics Explorer* is a product of Logal Educational Software.

allows students to input quantitative information and view output in graphical displays, model "action" displays, and spreadsheet data table displays. The teacher planned the week-and-a-half unit of study on circular motion, which is equivalent to three weeks in a regular six- to seven-period day since the school is on a blocked schedule of 90-minute periods. Students were to complete two *Physics Explorer: Gravity* simulations, *Circular Orbits* and *How "Heavy" Is a Planet?*; two videotapes and quizzes from the *Mechanical Universe High School Adaptation* series, *Circular Motion and Navigating in Space*; readings and problems on circular motion from Hickman's *Problem Solving Exercises in Physics* and Hewitt's *Conceptual Physics*; and a test (notes, April 3, 1995, file n43.eth).

The dialog below occurred about midway through the circular motion unit. The students had completed the *Interactive Physics II™ Simulations* activities, had watched and were quizzed on the *Circular Motion* videotape, had participated in demonstrations and lecture/discussions on circular motion, had read the physics text, had worked text problems relating to circular motion, and had completed *Physics Explorer Gravity: Circular Orbits*. They were familiar with the mathematical formulas associated with circular motion and had worked many problems using $F=GMm/r^2$. During the class period in which the dialog below occurred, the two students, Judith and Annita, completed the worksheet on *Circular Orbits* which involved analyzing the spreadsheet and graph for the linear relationship between orbital velocity (v) and orbital radius (r). As a part of the simulation experiment, the students had to add a calculated column to their spreadsheet, one over the square root of r ($1/\sqrt{r}$), and generate the graph, v versus $1/\sqrt{r}$. When they saw

the graph with the straight-line, positive slope, they understood that orbital velocity is proportional to one over the square root of orbital radius.

The objectives for the simulation, *How “Heavy” Is a Planet*, were to “simulate different circular orbits of an object around Earth, at different orbital radii (r), and find the corresponding values for the object’s period (T); analyze this data, using the spreadsheet to find the constant, K ; use this information to determine the mass of the Earth; and use this method to determine the mass of the Sun and the orbital radii of Venus and Mars” (Logal, 1991, pp. 48). Kepler found that for planets orbiting the sun, the period (T) is related to the semi-major axis (a) of the elliptical orbit by the relationship: $T^2/a^3 = K$. Thus K is the same value for all of the sun’s nine planets. For circular orbits, a is equal to the orbital radius so that the constant $K = T^2/r^3$. Since gravity is a universal force, the satellites around the Earth also display this relationship and students used the simulation to find the constant K for the Earth.

The display screen of this simulation has three main sections—boxes for variable input, the model or action area, and a graphical window area (see Figure 1). The graph generated is orbital radius/planet radius versus time (r/R vs. t). As the satellite orbits the planet, the graph is generated simultaneously. In this model, circular orbits exhibit flat graphs since r is constant for circular orbits.

The simulation has several pre-set parameters and assumptions (Logal, 1991). The time intervals for the orbiting object are pre-set by the software and are small enough “that each ‘step’ of the object’s motion results in a small change of the system’s state” (p. 29).

The mass of the planet (M) must be approximately 100 times as great as the mass of the satellite. The motion of the object is relative to a fixed space-reference frame, independent of planetary rotation. Since most of the experiments are performed in interplanetary space, the model does not take into account viscous forces such as air friction. This model assumes the planet is spherically symmetric and only circular orbits are considered.

There were four variables in this simulation—mass of the planet, radius of the planet, height above the planet that the satellite orbits, and orbital velocity. Two of these variables were pre-set—the Earth’s mass and the Earth’s radius. The students had to find the orbital radius (r), by adding the height and planet radius, and then calculating the orbital velocity (v) with the formula, velocity equals the square root of the Universal Gravitational Constant (G) times the mass (M) of the planet divided by the orbital radius ($v=\sqrt{GM/r}$).

The dialog below begins as Judith and Annita were just getting started on the second simulation, *How “Heavy” Is a Planet?* They booted up the program, selected from a series of menus, and did a Find File search to get into the correct program. Judith and Annita entered the height and orbital velocity in the variable boxes and selected Run. They observed two actions at once, the movement of the orbiting satellite and the generation of a graph, r/R Vs. time. The satellite orbited according to the data input; it either achieved a closed orbit around the planet, crashed into the planet, or flew off into space. Students could tell in seconds if the input parameters were correct. If the satellite achieved a successful circular orbit, the graph was flat. When the trial run was successful, students

were directed to collect the data into the spreadsheet part of the program by pressing a Record button.

The dialog was taken from the transcription of the student videotape of April 4. Annita and Judith were one of ten groups of students who worked on the computer simulations at their own pace. The teacher walked around the classroom and monitored student progress. Annita and Judith asked for help and he came to help them get started. He spent several minutes with Annita explaining how to find the orbital radius since this program differed from *Circular Orbits*. In *Circular Orbits*, the orbital radius was the variable and the difference between height and orbital radius was not addressed. In this simulation, the students had a fixed planet radius and varied the height of the object above the planet. The students had to find the orbital radius by adding height and radius of the planet. (Transcription of student tape, VHS-C camera, period 1, April 4, file cp144)

- 171 Annita: Hey, Judith. To get the
172 orbital radius you have to add the
173 green to the purple. [She pointed to
174 the two distances on the simulation
175 model.]
176 The distance from
177 the green to the purple. [She pointed
178 to the planet's edge and center.] And
179 the distance from the blue to the
180 green. [She pointed to the satellite
181 and the planet.]
183 Judith: Un hunh.
185 Annita: Judith, didn't you just do
186 the height?
206 Judith: All right, we need it at 7926.3.
208 Annita: Did you add both of those
209 together to get that?
211 Judith: No, I square rooted it
212 because we had v squared equals this.

214 Annita: [Looked strange ... like she was
215 questioning the value Judith
216 calculated.]
243 Annita: You've got to add those two!
245 Judith: No.
251 Judith: [Judith took control of the mouse
252 and keyboard, inserted the value she
253 calculated for v, and pushed the Run
254 icon. The satellite left the orbit
255 and ran off the screen.]
257 Annita: Judith!
259 Judith: [Laughed.]
261 Annita: Thank you Judith for not
262 listening to me.

Later, after a couple of tries that had miscalculations, the girls were finally successful.

315 Annita: I'm adding them ... OK 5687.9.
317 Judith: I don't think so.
318 [Judith entered the value for v and pushed
319 the Run icon. The satellite orbited
320 the planet and the graph was flat.]
322 Good job!
324 Annita: See that has a straight line.
325 [She pointed to the graph of r/R Vs.
326 time.]
327 Now who figured it out?
329 Judith: All right, how did you do that?

Note: The line numbers correspond to the original *Ethnograph v 4.0* transcript of the videotape.

Analysis: Judith knew the equation, $v^2 = GM/r$; however, she did not understand that the r value was the orbital radius, not height or planet radius. Annita tried to help her to understand, "Hey Judith. To get the orbital radius you have to add the green to the purple. ... The distance from the green to the purple. [She pointed to the planet's edge and

center.] And the distance from the blue to the green. [She pointed to the satellite and the planet]" (lines 171-181). Annita could not make Judith understand that her calculations would be off if the wrong radius was used, "Judith, didn't you just do the height (lines 185-186)? ... Did you add both of those together to get that" (lines 208-209)?

Judith wanted to make sure that she took the square root of GM/r to get the velocity and responded, "No, I square rooted it because we have v^2 equals this" (lines 211-212). She did not understand that the radius was different in this simulation than in *Circular Orbits*. The value for orbital velocity that Judith calculated was off and she knew it instantly (lines 251-255). After Judith input the value and selected RUN, two things happened at once—the action model of the satellite orbiting the planet began but the satellite quickly veered off to the right of the screen and disappeared from view, and the graph had a negative slope. Because the girls had selected Trace, a dotted line illustrated the satellite's path off of the screen. Both students knew immediately that there was a problem and they laughed (line 259). Annita exclaimed, "Judith" (line 257)!

Annita understood that the r value in the calculation was the problem and said, "Thank you Judith for not listening to me" (line 261-261). Annita and Judith both began to calculate a new value for velocity. Annita got the value first and said, "I'm adding them ... OK. 5687.9" (Line 315). Judith still doubted, "I don't think so" (line 317). When she saw the orbit was circular and the graph was flat, Judith congratulated her partner, "Good job" (line 322). Annita had to brag a little, "See that straight line" (line 324). Judith was now ready to learn what Annita was trying to share, "How did you do that" (line 329)?

Discussion: The students had worked math problems related to circular motion, the teacher had lectured and demonstrated circular motion using a ball on a string, but students still had trouble understanding the vocabulary and symbolic representations in the formulas. There are several observations that need to be explored from this dialog—the students were actively engaged in learning from each other, from the teacher, and from the computer software; the teacher acted as a facilitator to get the students started and then left the group to work on their own; the computer software gave immediate feedback to help the students to better understand their errors; the computer software could do what other teaching methods could not do, simultaneously illustrate the relationship between the mathematical formula, the physical phenomena, and the graphical representation of the event.

The team of two students working together was more effective than either student would have been working alone. Judith learned from Annita and Annita had the opportunity to verbalize her understanding. Judith and Annita were on task during the entire observation. Judith was the self-appointed leader as exhibited by her taking control of the mouse, entering all data, and doing the calculations without really listening to Annita. Annita was not a weak participant, however. She continued to persist in sharing what she discovered from the teacher and the software. Only after the obvious error in calculation was illustrated by the action of the satellite flying off into space, did Judith stop and listen. The pair worked together and learned from each other; the teacher intervened for only a few minutes at the beginning of the experiment. In the end, Judith did not want

to merely accept that Annita knew how to calculate the velocity, Judith wanted to learn how to do it for herself. The laughter, joking, and light embarrassment exhibited by the students illustrated the non-threatening atmosphere of learning that the teacher and the technology provided. They simply tried again when they were wrong.

The teacher was able to capitalize on a teachable moment to explain to Annita the critical difference between this program and *Circular Orbits*—the orbital radius was not given directly but had to be calculated by adding the planet's radius to the height. He left the group when he knew that Annita understood and could help her lab partner to understand. The technology facilitated the ability and skill of the teacher to enter at critical points in the learning process. It gave the teacher the ability to work with students who needed help and to monitor student progress during the entire class period. The prior planning of the teacher in arranging computers around the perimeter of the room and pre-loading software programs also facilitated the classroom management of the teacher. In this case, he went to Annita and Judith when they asked for help at the beginning of the activity. He did not return to the group for the remainder of this class period.

The software had several user-friendly components that enabled the students to learn. As Annita pointed out, the use of color in the model enabled the two students to talk about the different radii and they better understood what orbital radii really was. Judith did not understand at first and she would not listen to Annita when she tried to explain how to find the orbital radius. Only after visually seeing what happened—the

satellite veering out of orbit or crashing into the planet—did Judith understand that the calculations were wrong.

The students used the graphical representation of the movement of the satellite to draw inferences from their data. The graph of orbital radius/planetary radius versus time in the first trial run had a negative slope. The students associated the animation of the satellite with the graph since it was generated concurrently with the movement of the satellite. They expected to see a flat line, zero slope, if the satellite had a successful orbit. The physical movement of the satellite off of the screen and the not-flat line was interpreted as an error in the mathematical calculation. Annita reasoned that the orbital radius and therefore the orbital velocity were wrong. When she recalculated the orbital radius and the orbital velocity, the model performed as expected and the graph was flat. No lecture or demonstration can instantaneously graph a motion such as a satellite orbiting a planet. The three components, provided by the computer, together—changing the height and velocity variables, modeling the planetary motion, and graphing the planetary motion—were powerful in helping the students to better understand orbital motion and the relationship of velocity and orbital radius.

Simulations in science are frequently used as a part of the research process. The models of physical phenomena help people to visualize motions or events that can be directly observed. For example, hands-on experimentation of orbital motion in the physics laboratory is impossible. Use of the model complemented the students' study of the work of Tycho Brahe, Johannes Kepler, Sir Isaac Newton, and Henry Cavendish. Students

conceptualized Kepler's laws and better understood how the mass of a planet can be calculated by observing the period and orbital radius of an orbiting object.

The spreadsheet enabled students to record acceptable data—circular orbits—and then compare findings for patterns. Later, when Judith and Annita recorded five acceptable sets of data, they went to the spreadsheet data table area of the software program. The simulation's spreadsheet had several columns of data including orbital velocity (v), orbital radius (r), and period (T) squared divided by orbital radius cubed (T^2/r^3). The T^2/r^3 column was fairly consistent and it was observed that the girls took the average of the values as the constant K for the Earth. They used the K to calculate the mass of the Earth and then applied Kepler's third law to find the K for the Sun and the mass of the Sun. The computer simulation helped students in learning and applying concepts related to the motion of planetary objects.

In conclusion, this dialog illustrated that:

- Cooperative or collaborative learning is facilitated with the computer.
- Computer simulations enable students to better understand the relationship between the mathematical formula, the physical phenomena represented by a model, and the graphical representation of the event.
- Students actively participate in their own learning when they use simulations.
- Computers enable students to collect multiple data sets in a short period of time and to display the data in a graph concurrent to data collection.

- Computers provide immediate feedback to the students to enable them to understand probable sources of error and re-do experiments.
- The role of the teacher changes from being a disseminator of information to the whole class to one of providing more assistance to individuals or small groups of students as teachable moments arise.

Example of Interactive Physics II™ Simulation, Study of Momentum

Interactive Physics II™ is a computer-based Newtonian simulation that allows students to explore different worlds of motion by changing variables to “see” what happens. The exploration can be quantitative with optional data meters appearing on the screen to record values of variables such as velocity, momentum, energy, acceleration, or force at every point in time. In addition, a graph can appear to trace the motion versus time, and the actual simulation is enacted on the screen. Thus, there are several things for a student to track at once.

In the dialog featured below, Suzi and Sandra were studying elasticity and conservation of momentum using a commercial product based on the *Interactive Physics II™* software, *Interactive Physics II™ Simulations*, by Addison-Wesley Publishing Company, Inc. The objectives in *Rocket Sled I* were to discover the difference in elastic and inelastic collisions and to show that the total momentum of the system was conserved in both types of collisions. Students read the printed materials that accompanied *Rocket Sled I and Rocket Sled II* and wrote their responses on a separate laboratory report. In this particular program, two rocket-powered sleds appeared at the top of the screen and the

students engaged in a scenario in which they used the sleds to transport ore for a mining company on an ice-covered planet. The bumpers on the sleds could be altered to increase or decrease their elasticity. One sled was an engine sled and the other was a freight sled. In the first scenario, the sleds had the same mass and the initial speed of the engine sled was 4.00 m/s. Students changed variables: speed of the engine sled, mass of the engine sled, and elasticity of the collision.

There were three main sections to the screen—the action area, the variable meter area, and the results meter area (see Figure 2). In the action area, the sleds moved according to the mass and velocity values that were assigned. There were also Run and Reset buttons in this section of the screen. The Run button could be selected by moving the cursor over the button and clicking on it. The sleds moved immediately after the Run button was selected and stopped automatically when the simulation ended. At anytime during the simulation, it could be stopped by clicking on the Stop button or clicking the mouse. The Reset button was used to change the parameters of the simulated experiment.

The variable meters area, displayed on the lower left side of the screen, allowed students to change the parameters of mass, speed, and elasticity. The fixed meter area, on the right side of the screen, displayed the time in seconds as the simulation ran. Four additional meters displayed the speed and momentum of the engine sled and freight sled before and after the collision.

In the first exploration, parameters were pre-set—sleds with equal masses of 2.00×10^4 kg, engine sled with an initial speed of 4m/s, and elastic collision. Students selected

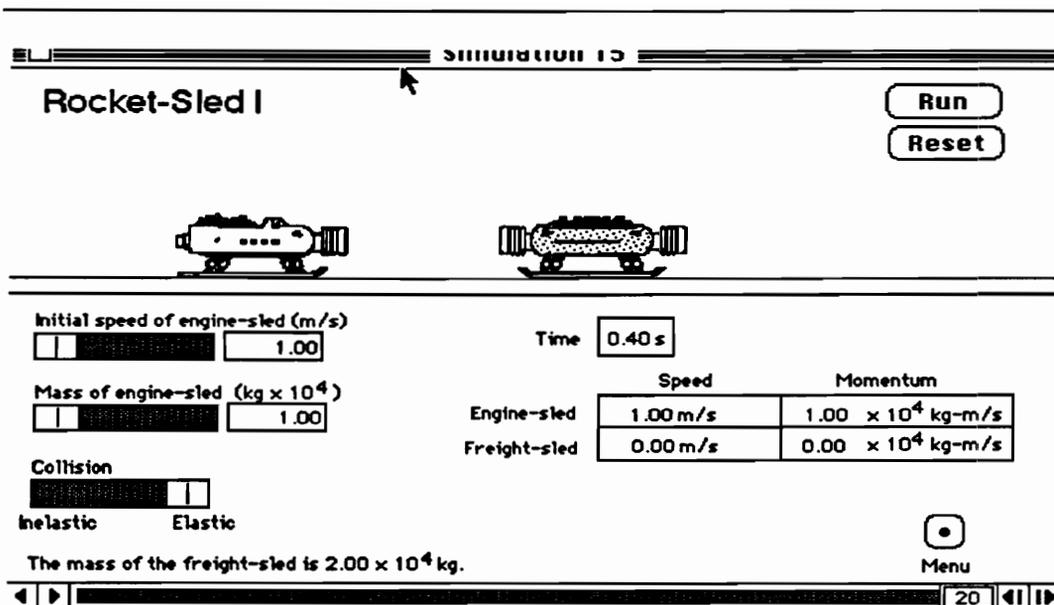


Figure 2. Screen display from *Interactive Physics II™ Simulations: Rocket Sled I*, by Addison-Wesley Publishing Company, Inc. Students input initial speed, mass of engine-sled, and elasticity; time, speed, and momentum meters change as the simulation runs.

Run and observed the collision. The students then changed the velocity of the engine sled to 8 m/s and observed the new momentum and velocity of the engine sled before the collision and the velocity and momentum of the freight sled after the collision. Next, the students changed the collision to inelastic, reset the simulation, and ran it again. The following dialog was taken from a transcription of the videotape of Suzi and Sandra as they discovered the differences in momentum of each sled in an inelastic collision.

(Transcription of student tape, VHS-C camera, period 1, April 26, file cp1426).

- 41 Suzi: Oh, the engine sled had
 42 the velocity to begin with and
 43 the freight sled had a velocity

44 of 0. When the collision
45 occurred, the engine sled stops
46 and the freight sled moves off
47 to the right.

49 Sandra: Well, it just doubled
50 the momentum. I mean when the
51 velocity doubled, the momentum
52 doubled. [She looked at the
53 meters on the screen.]

62 Sandra: How do we get the momentum?
65 Suzi: Multiply the mass
66 times the velocity.
68 Sandra: Are you sure?
70 Suzi: Yeah.
72 Sandra: The mass is 2.00,
73 correct?
75 Suzi: 2 times 10 to the 4th.
77 Sandra: The velocity is ...
79 Suzi: 8 meters/second. 16 times
80 10 to the 4th. No, Wait!
82 Sandra: Yeah! That's right. See
83 right here? [Sandra pointed
84 to the screen.]
86 Suzi: How come it's zero [the
87 engine sled momentum.] AH, it
88 stopped.
90 Sandra: Because it stopped.

94 Sandra: Now we need to do
95 inelastic.
97 Suzi: Lets see what inelastic
98 does. [Suzi moved the bar to
99 inelastic and selected Run.]
101 Sandra and Suzi: [Both girls
102 watched the screen as the engine
103 sled collided with the freight
104 sled and they continued to the
105 right together at a slower
106 speed.]
108 Suzi: OH! Inelastic ... They stay
109 together. Their velocity is

110 halved. The momentum was
111 halved. When they collided,
112 they came together, their
113 velocity was halved and their
114 momentum was halved.
116 In the beginning the velocity
117 was 8 m/s and after they came
118 together the velocity was 4 m/s.
119 [Suzi pointed to the boxes on
120 the screen.]
123 Suzi: Remember before that one [engine
124 sled] would stop and that one
125 [freight sled] would keep going
126 and that one [freight sled]
127 would take all of the momentum
128 that one [engine sled] had?
129 [Suzi used her pencil to point
130 to objects and values on the
131 screen.]

Analysis: The two students had a very weak understanding of momentum at the beginning of the simulation, even though momentum had been discussed in a lecture/discussion and an assignment was made to read about it in their text. Sandra (line 62) had to ask Suzi how to calculate momentum and they initially questioned why the momentum of the engine sled was 0 m/s after the collision (lines 86-90). The computer software screen display helped to reinforce the mathematical relationship of momentum to mass and velocity. Sandra noted, “Well, it just doubled the momentum. I mean when the velocity doubled, the momentum doubled” (lines 49-52).

After Sandra and Suzi made the simple calculation (lines 72 to 80), “The mass is 2.00 ... 2.00 times 10 to the 4th ... The velocity is 8 meters/second. 16 times 10 to the 4th.” Sandra noted that the calculated momentum was right because it was displayed on

the screen (lines 82 to 84). Sandra, “Yeah, that’s right. See right there?” The fact that momentum was zero when the sled was stopped was reasoned out by Suzi and Sandra as they thought through and analyzed information on the screen (lines 86 to 90.) “How come it’s zero? AH, it stopped.”

Before conducting the investigations, neither Suzi nor Sandra seemed to understand the difference between elastic and inelastic collisions (lines 94 to 99.) Suzi, “Lets see what inelastic does.” After viewing the inelastic collision on the computer screen, not only did they have a visual image of the carts sticking together in inelastic collisions, they also noticed immediately that the velocity and the momentum of the engine sled was halved in this experiment (lines 108-114) when it collided with the stationary freight sled. Suzi, “OH! Inelastic ... They stay together. Their velocity is halved. The momentum was halved [engine sled meter readings]. In the beginning the velocity was 8 m/s and after they came together the velocity was 4 m/s.“

After the simulation ran, Suzi continued to distinguish between elastic and inelastic as she explained what happens to momentum in elastic collisions of equal masses (lines 123-131). Suzi, “Remember before that one [engine sled] would stop and that one [freight sled] would take all of the momentum that one [engine sled] had?”

Discussion: While a demonstration by the teacher could illustrate elastic and inelastic collisions, the relationship of velocity, mass, and momentum could not be instantly seen and understood, nor connected to the elasticity of the collision. In this simulation, the students were able to see the action—two sleds colliding—and they were

able to see the values of the velocity and momentum for each sled before and after the collision. The abstract concept of inelastic collisions was made concrete by the motion of the sleds on the screen and the display of the values of velocity and momentum. One of the limitations of this simulation was that it did not allow for other types of inelastic collisions other than “sticking together.”

Due to concrete illustrations of elastic and inelastic collisions, the students better understood the relationship between velocity and momentum. They understood that when the velocity is zero, the momentum is zero. They also understood that in inelastic collisions similar to the one studied in this simulation, between a stationary object and a moving object of equal masses, the velocity of the moving object is halved and its momentum is halved. Suzi’s connection of the mathematical relationship to the physical action was clearly evidenced. Mathematics is the language of physics and teachers strive for students to transfer physical phenomena to mathematical symbols and equations. In this simple case, the computer software facilitated that transfer for these two students.

After this dialog, the students continued to the second part of the activity where they completed two data tables, one for an elastic collision and one for an inelastic collision. In the elastic collision, they were given the mass, speed, and momentum of the engine sled and the freight sled and the total momentum before the collision; they calculated and reasoned what these variables were after the collision. In the inelastic collision, they were given the mass, speed, and momentum of each sled and the total momentum of the system; they calculated the variables before the collision. After

completing the table, they input the values of mass, speed and elasticity into the simulation software and ran the experiment. They compared and confirmed their calculations with the values in the meters on the screen. Using the fixed meters that recorded the speed and momentum of each sled before and after the collision, they could see that the total momentum was conserved in either type of collision, just as they had calculated in the data table. In this case, the computer software helped to reinforce learning.

In a traditional setting, problems could be worked and demonstrations conducted, but there was no way to display the velocities and momenta of objects immediately after they collide. The computer allowed students to instantly put both the visual image of the physical phenomena and the corresponding mathematical relationship of velocity and momentum into a framework that they used to understand the concept.

Suzi put the definition of elastic into her own words, “It is like ... an exchange of velocity and momentum. Whereas inelastic upon collision ... velocity is halved.” Sandra added, “It is velocity and momentum, right?” Both girls by the end of the activity were able to explain conservation of momentum in elastic and inelastic collisions, calculate momentum, and apply what they learned in a new situation—Rocket Sled II.

In Rocket Sled II, they applied their knowledge in two computer situations: one in which they had to propel the freight sled across a deep crevasse with the engine sled stopping just before plunging into the crevasse and another in which both the engine and freight sled had to collide with enough momentum that they both flew across the

crevasse. The girls were observed to apply and to reinforce the concepts learned in the first simulation in the follow-up activity.

In conclusion, in this dialog:

- Abstract concepts in physics were made more concrete with the use of computer simulations.
- Students connected mathematical formulas with the physical phenomena displayed in the simulation.
- Students collaborated and actively participated in their own learning.
- Students were able to put into their own words definitions for physics terms such as elastic and inelastic.

Example of Computer-Based Probeware Experiment, *Impulse and Momentum*

This laboratory experiment represents the second example of an activity from the conservation unit. During the class period in which the dialog below occurred, students worked on two conservation of momentum activities, an *Interactive Physics II™* simulation of momentum (p) and impulse (J), “ p and J Study,” and a teacher-made probeware laboratory experiment, *Impulse and Momentum*. Since photogates for the computer-based probeware experiment were limited, five groups of students worked on the simulations while five others worked on the *Impulse and Momentum Lab*. Both activities were to be completed within two class periods. Only the computer-based probeware experiment is examined in this example.

The experiment featured in this story was adapted from a *PSSC Physics* lab, *Momentum Changes in an Explosion*, which examined the momentum and impulse in an “explosion” of dynamics carts. The carts are pushed away from each other by a sudden force. The adapted lab experiment used two photogates, Pasco dynamics carts, a Universal Laboratory Interface (ULI), and a Macintosh computer with Vernier *ULI Timer* software (see Table 2). The experiment was conducted on a long flat table placed next to the computer. The photogates and carts were placed on the table and the photogates were connected by a cable to ULI device attached to the computer (see Figure 3).

The photogate is a device that can be used with the ULI to measure time intervals much more accurately than can be done with a stopwatch. The photogate consisted of an infrared light-emitting diode (LED) and a light sensitive device, a photodetector, that are placed opposite each other within a plastic frame. The ULI monitors the voltage output from the photodetector, which varies as the light path is blocked and unblocked. The ULI’s hardware has a built-in timer which notes the time of a change in voltage at either digital input. This time, in microseconds, is sent to the computer and is interpreted by the *ULI Timer* software. The *ULI Timer* software then displays the data in meaningful formats.

Velcro strips were located on the bumpers of both carts and could be used to attach the carts together. The carts were placed close together in the center of the table and a spring-loaded plunger, in one of the carts, was pushed in and set in place. The trigger mechanism on the plunger-cart was released by the forceful, precise hit of a

meterstick held by a student; thus the carts were instantaneously propelled in opposite directions by the spring. The carts then passed through photogates, about thirty to forty centimeters from the explosion, where the time to block and unblock the photogate was measured and sent to a computer. Each cart had a small “flag” made from a 4 x 8 index card which passed through the photogates. With the length of a flag and the time known, the computer calculated and displayed the velocity of each cart in a spreadsheet format.

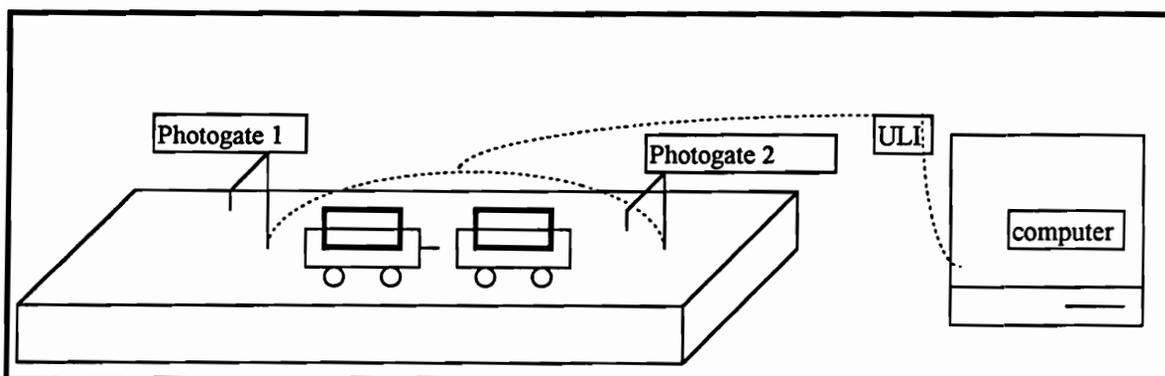


Figure 3. Drawing represents photogates and dynamics carts on a table with cable connections to ULI and computer.

In the traditional PSSC lab, *Momentum Changes in an Explosion*, time was not measured directly. The carts had to be carefully placed on the table at such a distance that the carts would hit the barriers at the ends of the table at the same time, producing an

auditory sound. This lab required great skill and many practice runs to get the carts to hit at the same time. After the carts had the same “clank” time, the students measured the distance of travel, and calculated the velocity in meters per “clank” and the momentum in kilogram meters per “clank” (kg m/clank). Experimental error was relatively large, and when different combinations of masses were placed on the carts, the error increased. Students questioned the unit kg m/clank instead of kilogram meters per second (kg m/s).

This photogate probeware and computer-based laboratory experiment enabled students to collect multiple sets of data during a class period, evaluate the data, and display the data in data tables and graph formats using common metric units of momentum. Compared to the results from the original PSSC lab, experimental error decreased. When large errors were noted, students used problem-solving skills to search for the cause of the errors and corrected them. As data are collected, they are evaluated by the students and the teacher for consistency and validity. In the following dialog, the teacher stopped to work with Caleb and Candice when he monitored their work and found inconsistent data displayed on the computer screen. (Transcription of teacher tape, stationary camera, Period 1, April 28, File p1428)

2559 T: You got a real big difference
2560 in yours.
2562 Caleb: [Caleb looked at the data
2563 table.] Every other one is
2564 ... um ...
2566 T: Go to your Data Edit Setup
2567 real quick for me. I just want
2568 to look at that. [Candice
2569 operated the computer.] Wait a
2570 second. Scroll upwards for me.
2571 OK. Go to File. How did you

2572 figure that out there?
2574 Candice: From the arrows.
2576 T: Good job. Go to the other
2577 one and press it. Up top I
2578 want to see delta t1. Up at
2579 the very top. You can leave
2580 them set like that if you want.
2581 The very top one is delta t1.
2582 The arrow again ... There you go,
2583 Good job. That's OK, I just
2584 wanted to check that arrow
2585 again. You can Close that
2586 Window.
2591 T: You should be finding that
2592 since the carts have about the
2593 same mass, they have about the
2594 same velocity. You are getting
2595 a pretty good difference
2596 between them. I know the
2597 second one was a mess but you
2598 should be closer. That one and
2599 that one ... that's a
2600 difference of a tenth of a
2601 meter per second. That's a
2602 pretty good difference. I am
2603 not sure what is going on
2604 there.
2605 Do another trial
2606 here. I want to see
2607 something.
2608
2610 Annette: Mr. Johnston
2612 T: You guys will have to wait,
2613 Annette. You guys are working
2614 out fine.
2615 Let's go ahead and put a little
2616 Velcro there.
2617
2619 Caleb: A little.
2621 T: Yeah, that's OK there. I'm
2622 going to make a suggestion.
2624 Caleb: I had them like this.
2626 T: Yeah, that is what I was
2627 going to say because of the ...
2628 T: It is not hitting those cords, is

2629 it?
 2631 Caleb: Yeah.
 2633 T: That messed it up a little
 2634 bit. Let's put that there. Go
 2635 for it.
 2637 Caleb: [Caleb released the carts and data
 2638 were collected.]
 2640 T: That's much better. You've
 2641 cut your difference. Remember
 2642 it was 0.1 before and now it is
 2643 .05. That is much better. The
 2644 second row of data there is
 2645 where you pulled them back
 2646 through the gates. You can
 2647 just ignore that data. You can
 2648 just leave that running if you
 2649 want. Set it up again. I'd be
 2650 consistent with your Velcro.
 2652 Caleb: [Caleb reset the trigger,
 2653 placed the carts in position.
 2654 Candice watched from the
 2655 computer. Caleb hit the
 2656 trigger and the carts rolled
 2657 through the photogates. Data
 2658 collected on the screen.]
 2660 T: So there you have a big
 2661 difference of .8. I want you
 2662 to see something Look at
 2663 your table. Is this gate 1 or
 2664 2?
 2666 Caleb: 2.
 2676 T: Watch what happens to the
 2677 cart if I let it go. What
 2678 happens?
 2681 Caleb: It rolls.
 2683 T: What does that mean?
 2685 Caleb: It's not lev ...
 2687 T: Means your table is not level.

The teacher and students worked for several minutes putting several washers under the table legs to make the table more nearly level. They rolled the carts through the gates and when they finally thought that the

table was as close to level as it could be, they did additional trials to test the data for consistency.

2745 Caleb: [Caleb hit the trigger
2746 mechanism and the carts rolled
2747 through the gate.]
2749 T: That's a lot better. Try it
2750 again.
2759 Caleb: [Hit the trigger and the
2760 carts went through the
2761 photogates.]
2765 T: How's that? Look at that!
2766 Good. .4517 and .4582.

Analysis: The dialog illustrated how the teacher and students evaluate data that are collected and displayed; and based on that evaluation, how they problem-solve to correct experimental errors. When data were found to be inconsistent, a series of systematic problem-solving strategies were set in place that allowed students to correct the problem and collect new data during the same class period. The problem solving strategies used by the teacher were to look for sources of error in many places—the computer software, the connections, the techniques used by students in performing the laboratory experiment, the dynamics carts and photogates, and the physical environment.

The teacher first checked the software to make sure that the parameters of timing were set correctly in the software program “Go to Data Edit Setup” (line 2566). From the Setup menu, students defined the timing intervals and formulas they needed in the experiment. Timing began on each photogate when the light beam was blocked and ended when the photogate's light beam was unblocked. The students correctly figured out the timing parameters by themselves. Teacher, “How did you figure that out there” (lines

2571-2572)? Candice, “From the arrows” (2574). Teacher, “Good job” (Line 2576). The Start and End selections had choices that were revealed by clicking on the arrows on the boxes—”Gate One Blocked, Gate Two Blocked, Gate One Unblocked, Gate Two Unblocked.” In addition, the students had correctly measured the width of the flag (distance) that passed through the photogates and input 0.10 meters into the “length window.” Based on the input of distance and time, the computer calculated the velocity of the carts in meters per second. When the teacher had checked all of the input parameters, he responded, “Good job. That’s OK, I just wanted to check that arrow again. You can Close that Window” (lines 2583-2586). The teacher knew that the students had correctly set the parameters in the software program.

In the dialog, the teacher evaluated the data from several trial runs that were displayed in a data table on the computer screen. He told the students what he expected to see, “You should be finding that since the carts have about the same mass, they have about the same velocity” (lines 2591-2594). However, the students were not getting consistent data. Teacher, “You are getting a pretty good difference between them” (lines 2594-2596). Both the teacher and students understood that the second set of data represented a rebound of the cart back through the gate and should not be counted, “I know the second one was a mess” (lines 2597-2598). He admitted that he did not know what was causing the error, “I am not sure what is going on there” (lines 2603-2604). The teacher continued to model problem-solving strategies as he tried to determine the sources of error.

The second problem-solving strategy the teacher modeled was to observe the experiment and the technique that the students used in triggering the “explosion”; so he asked, “Do another trial here. I want to see something” (lines 2606-2608). The teacher noted cords that could have been in the path of one of the carts thus slowing it down. “It is not hitting those cords, is it” (lines 2628-2629)? After moving the cords, students did two trials that had very different velocity data—0.05 m/s in one trial and 0.80 m/s in the next trial. The students and the teacher knew something else was wrong.

Looking around at the physical environment of the table, the teacher noticed that the caps on one set of the table legs were missing which caused the table to not be level. Teacher, “I want you to see something. Look at your table. Is this gate 1 or 2? What happens to the cart if I let it go? What happens? ... Means your table is not level” (lines 2661 - 2571). The teacher and the students worked for six minutes trying various numbers of washers to level the table. When they thought it was level and the dynamics carts did not roll freely without an applied force, they tried additional trial runs. Finally, they collected data that were acceptable. Teacher, “That’s a lot better. Try it again. How’s that? Look at that. Good .4517 and .4582” (lines 2749- 2766). The teacher left this group of students only after they were able to proceed on their own to collect acceptable data and complete the experiment.

Discussion: Five main ideas emerge from this dialog: (1) the teacher showed skill in planning and implementing the use of technology that included strategies for monitoring student progress and helping the neediest students; (2) the technology enabled

students to collect and evaluate data, problem solve, and interpret graphical output; (3) students had an understanding of physics vocabulary and concepts as well as vocabulary unique to the computer; (4) the teacher assessed student performance and understanding of the technology; and (5) students used the computer to help them evaluate data and to take special care in performing the experiment in a manner that minimized extraneous variables from interfering with the experiment.

The teacher's placement of the computers on the perimeter of the room enabled him to monitor student progress and to help those students who needed his help. He observed the computer screens as he walked up and down the central aisle of the classroom. The teacher used the technology and his judgment to determine who needed help. As he monitored student progress, he observed computer displays of the spreadsheet data tables and evaluated the data from each group of students.

In this example, he observed Caleb and Candice had collected several sets of data with wide discrepancies in velocity. The velocity data, which should have been approximately equal for gate one and gate two, varied greatly. The teacher stopped and gave this group his undivided attention for approximately nine and a half minutes as they, the teacher and students together, identified sources of error in the experiment and corrected the problems. At one point he told another group, who wanted his attention, "You guys will have to wait. You guys are working out fine." In his monitoring of student progress, the teacher had noted that the group asking for help had excellent data. He had just confirmed that their data and technique were acceptable, "Look at that. Pretty

good, huh? You guys are experts at it.” The teacher used the technology—computer and software—to assist him in knowing which students needed his help. As a result, by the end of the period, all groups of students had consistent, accurate data from which they were to analyze and draw conclusions about conservation of momentum.

The computer and photogates enabled the students to repeat the experiment several times. In the above dialog, Caleb’s and Candice’s data were not consistent and the velocity of the cart through gate two was always higher, although the differences varied. The teacher noted the problem and assisted the students in solving the problem so that they had five good sets of data by the end of the period.

In traditional data collection, because it takes so much time to set up and measure time and distance for each trial, the majority of class time is spent in collecting data and a minimum amount of time is spent in evaluating the validity of the data. This limits the opportunities for students to discuss and evaluate the data. Students frequently do not know that the data are erroneous until after they try to do the calculations and data analysis alone at home. In this experiment, the computer allowed the students and the teacher to question the data, analyze the problem, correct the problem, and do several retrials in a short period of time. Once the sources of error were corrected, five sets of data were collected in less than five minutes. The students were able to complete the calculation of momenta of the carts and to compare the momentum of cart 1 with cart 2.

Another point that is worth discussing is that the students and teacher had a common understanding of the vocabulary of physics. In the example above, they

understood the terms velocity and momentum and their corresponding units—meters per second and kilogram meters per second.

The teacher evaluated their understanding of the vocabulary as well as their understanding of the experimental variables that had to be entered into the software. He assessed their performance when he checked to see if they had input the length of the index card and set the timing parameters correctly so that the computer could calculate velocity. Everything was correct. The students had figured out the distance was the length of the index cards and the time was the time for the cards to pass through the photogates. Later in the class period, the students calculated momentum and impulse. The computer could have automatically calculated momentum, but in this instance the teacher chose to have the students reinforce how to calculate these values using the formulas $p=mv$, $\Delta J=\Delta p$, $\Delta p=m\Delta v$.

The teacher assessed understanding of the calculations when he asked Caleb how to find the impulse imparted to the left and the right cart. Caleb replied, “You would take the momentum at rest and find the difference between it and the momentum after it crossed the photogate” (lines 3217-3221). Caleb understood that momentum was the mass times the velocity as was evidenced in his calculations. He further understood the relationship between impulse and change in momentum.

In the example above, the students understood not only physics vocabulary and calculations but computer-related vocabulary as well. Computer terms used in the above example included File, Edit Data Setup, Close, Window, scroll, and click. The teacher

used these terms and the students did not ask for clarification but performed the computer task the teacher directed them to do.

The computer enhanced the student's ability to detect deviations from expected results. They identified extraneous variables and carefully conducted this experiment with as many variables controlled as possible. Because the table was not level, one of the carts accelerated as it rolled down the table and the other cart decelerated. The immediate output to the computer in the form of velocity data enabled the teacher and the students to note inconsistent data. The computer increased the students' ability to evaluate data, to detect errors, to adjust lab techniques, and to carefully conduct experiments.

In conclusion, the students and the teacher engaged in meaningful dialog and interactions when the computer, photogates, and dynamics carts were used to study momentum. The following points were clearly illustrated through their interactions and dialog.

- Students collected data from multiple trial runs of an experiment in a short period of time.
- Students and the teacher used the computer display to evaluate data.
- The teacher used the opportunity to model problem-solving techniques.
- Students had opportunities to examine and correct sources of error.
- The teacher devoted more time to those students who needed help.
- The teacher used the data output from the computer to evaluate student progress.

- Teachers and students had more fruitful conversations and interactions because students understood the vocabulary of physics and the vocabulary associated with the computer technology.
- The teacher took advantage of opportunities to evaluate student performance and understanding.
- The computer enhanced the students' ability to conduct a careful experiment.

Example of Computer-Based Probeware Experiment,

Smart Pulley Lab on Impulse, Momentum, Work, & Energy

As the students progressed in their study of conservation, they examined not only momentum but also energy. This quantitative probeware experiment on the conservation of momentum and energy enabled students to conduct an experiment that could not be conducted in a traditional classroom without computers. The Pasco Smart Pulley (see Table 2), a timing device, was used with the Universal Laboratory Interface (ULI), and the *ULI Timer* software. Timing conducted in this experiment could not be done using stop watches with the same degree of accuracy. In addition to the increase in accuracy of the time measurement, students were able to collect several data sets during the class period. In traditional classrooms, students could not have collected, evaluated, graphed, and analyzed data from three trial runs during one class period.

This laboratory experiment was performed about three-fourths of the way through the scheduled study of conservation of momentum and energy. The teacher said in his pre-lab discussion, "Remember your purpose here is two-fold. Remember that you need to

show that $F \Delta t$ is equal to $m \Delta v$ and you need to show that $F \Delta d$ is equal to ΔE_k " (file p2428.eth, lines 87-96). Table 3 explains the symbols and terms used throughout this dialog. Students had two options for data collection and analysis in this lab—to use data from Newton’s Second Law Lab done previously or to set up the apparatus and collect new data.

Table 3

Symbols and Terms Used in Smart Pulley Lab

Quantity/Term	Symbol.	Quantity	Symbol.
Force	F	Mass	M
Delta (change in)	Δ	Velocity	v
Kinetic Energy	E_k	Impulse	J
Work	W	Momentum	p
Time	t	Distance	d

Equipment for the experiment—a Pasco dynamics cart and a Pasco Smart Pulley—were placed on a long flat table next to a movable cart with Macintosh computer and monitor. Cables connected the probe (Pasco Smart Pulley) to the computer through an interface box called a Universal Laboratory Interface (ULI) (see Figure 4). The “Ten Spoke Smart Pulley” file in the *ULI Timer* software enabled students to study the linear motion of the dynamics cart connected to a string that ran over the pulley and attached to

a 200 gram mass hanging over the edge of the table. The Smart Pulley probe had two components—a light sensitive photodetector and a light source, an infrared light-emitting diode. As the spokes turned, the blocked and unblocked light path caused a change in voltage output from the photodetector. The ULI monitored the voltage output from the photodetector. The Vernier *ULI Timer* manual (1995) explains, “The ULI includes a hardware timer that can be used to accurately time when the photogates are blocked or unblocked. The ULI relays the timing results to the Macintosh for display in the *ULI Timer* program” (p. 19).

In this experiment, the timing software, *ULI Timer*, worked with the timing and distance input from the ULI and the ten-spoke Smart Pulley to display output in the form of raw data, a spreadsheet data table, or a graph. A data table and a graph can be displayed simultaneously. Students selected from a series of menus to get the computer to collect time readings from the Smart Pulley. The Data Table window had multiple columns of data— Δt_1 , midtime Δt_1 , velocity, distance, time [distance], acceleration, time[acceleration] (see Table 4).

In this experiment, students used the midtime Δt_1 readings which were the cumulative time readings from the start of the experiment. The timing device, a Pasco Smart Pulley, and the timing data were described by the teacher, “The Smart Pulley is just a photogate except that it has a whole bunch of little things going past it. I think that the midtime delta ts are when the spokes go by at the middle of those (file p2428.eth, lines 318-324).” The software collected many different columns of time data and the students

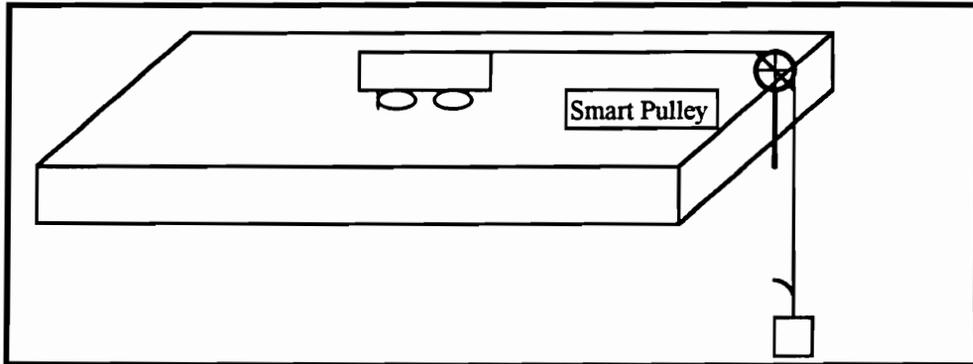


Figure 4. Drawing of cart, Smart Pulley, and hanging mass. The ten-spoke Smart Pulley connected to the computer through the ULI.

Table 4

Three Readings from Smart Pulley Data Table

$\Delta t 1$ (s)	Velocity (m/s)	Mid Time $\Delta t 1$ (s)	Distance (m)	Time [D] (s)	Acc. (m/s/s)	Time [A] (s)
0.0984	0.1525	1.786	0.015	1.8352	0.9161	1.8682
0.065	0.2277	1.8682	0.03	1.9011	0.8797	1.9279
0.0535	0.2802	1.9279	0.045	1.9546	0.9912	1.9774

Note. The columns of data displayed are from the 10 Spoke Smart Pulley file on ULI Timer.

and teacher had to decide which time data represented the time in which the force acted. After thinking through the possibilities, they concluded that the Mid Time Δt_1 was the correct time column to use in calculating velocity and impulse.

In addition to the *ULI Timer*, students used two other pieces of software in this experiment, a graphing/statistics program and an integrated utility software package with a word processor and spreadsheet. *ClarisWorks* word processor was used to write the laboratory report and *ClarisWorks* spreadsheet was used to create data tables for inclusion in the lab report. *Cricket Graph III* was used to statistically analyze the data which was included in the students' lab report.

Since students could, theoretically, use old data sets from the Newton's Second Law Lab, Susan, Noliana, and John first examined Noliana's old data set. Noliana's former lab group had saved the data to disk. After a couple of minutes of analysis, the group decided that they didn't have enough information and they had to redo the experiment. This process of assessing whether enough information is available to solve a problem is a very important skill in any scientific study. Using computer-based experiments and records allowed students to apply that skill.

The students concluded that they did not have enough information. Noliana, "I guess we are going to have to do everything again. Either that or borrow someone else's data who has a velocity-time graph" (file C428p2.eth, lines 132-139). John, "We don't have enough data with the ULI timer. The thing is, we only have one trial of data (lines 206-209.)" Susan, "We do not know the masses. We need to know the mass in order to

find the force” (lines 211-213). Susan and John realized what they needed to know and what information they didn’t have in order to examine momentum, impulse, work, and energy of the closed system. They explained to Noliana that one trial wasn’t enough data and that the masses of the hanging brass weight and the cart were unknown.

The three students worked together, one collected the equipment—dynamics cart, Smart Pulley, string, mass set, wood, and cables—while another set up the computer software to the timing device they were using and began to word process the lab report. The third one got a calculator and paper to record data.

The computer software enabled the students to know the time—midtime Δt —that the force (tension) acted, the velocity of the pulley and cart, and the distance the pulley and cart moved. They calculated the tension on the cart using the formula, $F = [m_1 m_2 / (m_1 + m_2)]g$. They calculated the change in momentum ($p = m\Delta v$) of the cart, the impulse ($J = F\Delta t$) that acted on the cart, the work ($W = F\Delta d$) done, and the change in the kinetic energy ($\Delta E_k = 1/2m(v_f^2 - v_i^2)$) of the cart. They also calculated the percent error or variance in their results—% Error = (difference between values/average of values) \times 100.

The following dialog represents interactions of the lab group—John, Susan, and Noliana—at several points during the laboratory experiment. At various times the students were joined by the teacher. The dialog was transcribed from three tapes, an audio tape of the student group (file acp2438t.eth), a videotape of the teacher from a stationary camera (file p2429.eth), and a hand-held camera that videotaped the student group (c428p2.eth).

In the first dialog, the teacher approached as John was setting up the apparatus. John connected cables from the Smart Pulley to the Universal Laboratory Interface (ULI) and from the ULI to the computer. He placed the Smart Pulley in the wooden holder, tightened a C-clamp securely against the wooden holder and table's edge, attached the string to the cart and the mass, and placed the string over the pulley. Susan manipulated the keyboard and mouse to save the lab report document that she had begun. She then selected the software file, 10 Spoke Smart Pulley, and set up the program to collect data.

As the teacher approached, John called out to get his approval of the way in which they had set up the apparatus. (Transcription of teacher tape, stationary camera, Period 2, April 28, File p2428.eth)

775 John: Look at that setup.
777 T: Plug it in. Turn it on. You
778 need an adapter [power]. What you need
779 is this and that goes into the
780 end of that and now you have got
781 power.
783 Now is that light coming on? ... on
784 your Smart Pulley?
786 T: Good job.
788 John: Yeah.
790 T: Good job. John, you might
791 need to turn that string 90
792 degrees. In other words, I
793 don't think that string is going
794 to clear. I think it is going
795 to drag on you. In other words,
796 turn it like that.

Analysis: The dialog represents the interaction of the teacher and students just as the students are in the set-up or pre-data collection process. The teacher monitored the

progress of each lab group and when he saw that John, Susan, and Noliana were ready to collect data, he returned to the group to check their set-up and make sure that data were recording. John said, “Look at that setup” (line 775), because he thought something was wrong. His initial trial run with the equipment resulted in no data readings on the screen. The teacher noticed immediately that the Smart Pulley did not have power. “Plug it in. Turn it on. You need an adapter” (lines 777-779). The teacher further modeled troubleshooting when he asked the students to look for the light on the Smart Pulley, “Now is the light coming on ...” (line 783).

Before the teacher left, he pointed out another problem that he observed—the string was binding on the wooden support block because it was placed with the wide side of the block over the edge of the table’s edge. The home-made rectangular wooden holder for the Smart Pulley, a piece of wood with a hole drilled in it, was held in place by a large C-clamp. John did not align the wooden holder properly with the table. T, “John you might need to turn that string 90 degrees. ... I think it is going to drag on you” (line 790-796). John repositioned the holder and the string hung freely over the edge of the table.

Discussion: The teacher is an integral part of the learning experience when students use computers. There are many places where errors could be made in this experiment—in the software set-up, in the connection of cables and power sources to apparatus, and in the physical arrangement of the cart, string, pulley, and mass. The students did not depend on the teacher for their every move but usually asked for his help when they either had a question or something didn’t work as expected. It is not easy to

know how much information to give students or to let them discover for themselves. In this example, maybe the teacher should have allowed a few more minutes for the students to “discover” the lack of power to the Smart Pulley and the drag on the string that would have caused experimental errors.

The teacher constantly monitored the ten groups of students and approached a group when they asked for help or he noticed a problem with students’ laboratory technique, the computer display, or the laboratory apparatus. In the case above, the student asked for help as the teacher approached. The teacher, with his experience, immediately noticed a problem with the electrical power to the Smart Pulley. He also noticed that the position of the Smart Pulley was ninety degrees off. When the students understood how to correctly set-up the apparatus, the teacher left the group and devoted his attention to other students. The students continued to work without assistance for the next few minutes.

Later, when the students were ready to actually collect and save data to disk for use in their lab report, the following conversation was transcribed. (Transcription of audio and VHS-C tape, hand-held camera station, Period 2, April 28, File acp2428t.eth)

- 252 John: Well, we want a little bit
253 more than minimum [number of trials].
254 Noliana: So, are we going to vary
255 the mass of the falling object
256 or the mass of the cart?
258 Susan: The cart.
- 263 Susan [Susan picked up a mass
264 and asked.] Is that two hundred
265 grams or two hundred kilograms?

266 [Even GT physics students still
 267 do not think metrically.]
 269 John: [John carefully measured the
 270 length of the table with the
 271 string and cut it so that the
 272 cart and mass system will move
 273 freely and the mass will just
 274 hit the floor.]
 276 Noliana: 200 kilograms.
 278 John: 200 grams!
 280 Noliana: So, we are not putting
 282 any weight on the cart?
 283 Susan: Not right now.
 285 + [John continued to work on the
 286 apparatus and Susan worked at
 287 the computer. John had the
 288 cart pulled back and the string
 289 taut and over the Smart Pulley
 290 attached to the mass. He had
 291 constructed a bumper by placing
 292 a large roll of tape in front of
 293 the Smart Pulley. The pulley
 294 was mounted to a small block of
 295 wood.]
 297 John: We are ready to roll.

Analysis: John wanted to collect more data than was the “minimum” acceptable amount. John, “Well, we want a little bit more than minimum” (lines 252-253). All of the students worked cooperatively and each one was involved in the experiment. Noliana was trying to understand exactly what they were doing as she asked questions, “So are we going to vary the mass of the falling object or the mass of the cart” (lines 254-256)? “So, we are not putting any weight on the cart” (lines 280-282)? John set up the equipment and he and Susan knew exactly what was going to take place. Susan took time to respond to Noliana’s questions so that she too would understand. To the first question

she responded, “The cart” (line 258) and to the second, “Not right now” (line 283). As noted above, the two girls, after twelve years of working with the metric system in math and science classes, still did not have a personal understanding for grams and kilograms. Both Susan and Noliana concluded that the falling mass was 200 kilograms (lines 263-264 and 275) but John set them straight when he caught their error and responded, “200 grams” (line 277)! The students worked together to get the equipment ready to collect data in the first trial run. John announced that he was ready, “We are ready to roll” (line 297).

Discussion: Three things are noted from the above segment—the students had high standards and continually evaluated the quality of their data, they worked in cooperative groups learning from one another, and the girls were active participants in the experiment. John’s standards were high and his previous experience in scientific investigations lead him to understand that conclusions should not be based on one trial.

John wanted to collect more than one trial of data and he knew that the computer and Smart Pulley made this possible. The students were able to collect data sets in approximately 30 seconds once they got everything set up and working properly. John knew the capability of the computer to quickly take data sets and display them in usable forms to his group; therefore, the drudgery of recording data in tables was not a problem. Students focused on the quality of the data to look for irregularities and patterns. John expected his group to have data from several trial runs to compare in examining the conservation of momentum and energy.

The computer probeware data collection system allowed the students to work in cooperative groups to share tasks and learn from each other and the teacher. Each person had a role. The roles of the group were not discussed, rather they just assumed the roles as they worked together without any discussion about who would do what. John took over the role of setting up the apparatus and Susan took the role of working at the computer. Noliana was the record keeper and the person in charge of mathematics calculations using a TI-82 graphing calculator to calculate impulse, momentum, work, kinetic energy, and percent error. The fact that the students were learning from each other will be evidenced more in the dialog segments to follow. The computer facilitated the collaborative learning of the students. In this dialog, the students' open conversation about the metric units (grams or kilograms) evidenced that the students learned from each other as they did the experiment.

Unlike what some research has found in some other science classes, the girls in this mixed gender group had very active roles in the laboratory experiment. Noliana and Susan contributed to the discussions, used computer and calculator technology and fully participated throughout the entire experiment. The task of conducting the experiment using laboratory equipment, the computer, and a calculator forced the group to work together to complete the task in a timely manner.

When the students made their first trial run, they had an interesting dialog about the validity of the data and the graphical representation of that data. The following is a continuation of the transcription of file c428p2.eth.

312 Susan: What is it doing?

314 John: That would be a ... BAD
trial.

317 John: Mark off those data there
318 and then it will come out good.

320 Noliana: You can make it a
321 positive slope. You have to
322 graph it.

324 T: Remember how we had to mark
325 those points invalid?

327 Susan: Yeah.

329 Noliana: Is this a negative or
330 positive slope? It was negative
331 wasn't it? [Two graphs were on
332 the screen.]

334 Susan: Redo it.

336 Noliana: Wait.

338 John: Make it shorter [the
339 string].]

341 Susan Yeah.

343 T: It is an error. It should be
344 a positive slope.

348 Susan: We'll just do it again.

351: John: [John cut the string,
352 and retied the cart
353 for the second trail. John and
354 Susan discussed the data.]

Analysis: Susan was the first to question the data that was being collected, “What is it doing” (line 311)? John joined in as he thought aloud, “That would be a bad trial” (lines 313-314). The students knew how to mark data invalid and re-graph without those data sets. John, “Mark off that data there and then it will come out good.” The teacher, as he monitored student progress, saw the graph on the students’ computer screen. He noted that the regression line through the data points on the velocity-time graph had a negative slope. He reinforced something the students had already discussed, the data were erroneous and parts of it could be marked invalid. The efficiency of the

software allowed the teacher to merely check for understanding. Teacher, “Remember how we had to mark those points invalid (lines 323-324). ... It is an error. It should be a positive slope” (lines 357-358). Susan responded, “Yeah,” because she had already marked some of the data invalid.

Susan continued to work with the data but did not get a positive regression line on the second try. She concluded that there were too many errors and the simplest thing to do was to run additional trials. She told her partners, “Redo it” (line 334). John noted a problem with the length of the string and decided to, “Make it shorter” (line 338). The students decided to reset the equipment and software and run the experiment again. Susan, “We’ll just do it again” (line 348-349).

Discussion: Three observations are made about the dialog—students analyzed data and problem solved using the computer data display formats of Data Table and Graph; the computer and software enabled students to collect, graph, and manipulate data in ways not possible before in traditional classrooms; and the teacher assumed the role as reinforcer of what the students learned for themselves.

Susan, John, and Noliana observed that the cart had careened into the barrier at the end of the table and bounced back. The timing device continued to collect data. In their analysis of what to correct before they reran the experiment, John realized there were two problems—the string was too long and the computer collected data from both the forward motion and the rebound of the cart before the stop button was pushed. He cut the string, reattached it to the cart and mass, and carefully placed it over the pulley.

The team tried two solutions to the erroneous data—marking it invalid and re-graphing and changing their lab technique of starting and stopping the data collection. Susan improved her technique by hitting the mouse button immediately when the cart hit the barrier, thus stopping the timing. John practiced catching the cart before it rebounded.

The students took advantage of a unique feature of the software, Susan highlighted and marked Data Invalid from the spreadsheet data table and re-graphed the data. *ULI Timer* allowed the students to “mark the data invalid”. In this process, a line is drawn through these data; they remain in the Raw Data spreadsheet but are not used in the subsequent calculations. This feature of the program reinforces the idea that scientists do not erase or delete data from the lab notebook; rather, a line is drawn through invalid data.

The second time the students graphed the data, they also had a regression line with a negative slope. They quickly realized that the data from their first trial were flawed and they did not want to waste any more time on it or use it in their lab report. They knew that they could collect several more data sets before the class ended so they set the cart in place and reset the software to collect another set of data.

The computer allowed the students to collect, evaluate, graph, analyze/adjust, and re-graph data in a short period of time. The Smart Pulley’s and ULI’s sampling rate allowed a plethora of data sets to be collected to the spreadsheet. The raw data contained distance and time measurements which were manipulated by the software to determine velocity and acceleration. Calculations and graphing take hours in traditional physics labs,

however; the computer calculated velocity and acceleration and then created a velocity-time graph all in a matter of seconds.

The teacher had a unique role in the above dialog. He was not merely a “giver of knowledge,” he listened to the students’ conversation and then reinforced what the students had learned for themselves. He reinforced that the first set of data were invalid, the slope of the regression line should have been positive, and the questionable data could be marked invalid thus eliminating it from the sub-set of data that was to be graphed by the computer. The students were actively involved in the learning and the teacher’s role, while still very active, was more a monitor-facilitator than a dispenser of knowledge. The teacher came to this group because he saw the negative slope of the regression line on the computer screen and he knew that there was a problem. He monitored and assessed student progress and returned to this group because he noted a problem. This is another example of the teacher being able to concentrate attention on students whom he thinks need assistance.

Under the watchful eye of the teacher, the students set up their experiment again. John and Noliana monitored the cart/pulley system and Susan manipulated the computer. When everything was ready Susan directed the trial run.

- 356 Susan: Are you ready? Ready?
358 Noliana: Right there?
362 John Pull it back more.
364 Susan: Is everybody ready?
366 John: Un hunh.
368 Susan: [Susan started the timing
369 program on the computer.]
371 Noliana: [Released the cart.]
373 [They all looked at the computer

375 screen.]
376 Susan: So how do we get that
377 section thing?
379 John and Noliana: Window. Data
380 Table. [Susan went to the
381 spreadsheet window and selected
382 what they wanted to graph—
383 velocity versus midtime Δt
384 1. She selected from a series
385 of pull down menus. Everyone
386 looked at the computer screen.
387 She highlighted a section of the
388 data at the end and deleted them
389 from the spreadsheet. They
390 watched the graph appear on the
391 computer screen.]
393 Noliana: Oh, YEAH!
395 Susan: DA TA DA DA! Yeah! [Susan sang out and went
396 from the graph to the spread
397 sheet to examine the data.]
399 John: We have a beautiful line!

Analysis: The students worked cooperatively with each person actively participating. Susan waited with her hand on the mouse button, ready to begin the timing when everyone was ready, “Are you ready? Ready” (line 356)? “Is everybody ready” (line 353)? They set up the cart and the computer software and did a second trial run. The computer processed the time data and displayed it on the screen in a spreadsheet format. Susan looked through the end of the spreadsheet for velocity readings that were negative and marked them invalid on the spreadsheet (lines 387-389). The students knew that the trial was successful when they saw the regression line through the data points on the velocity-time graph had a positive slope. They all reacted with smiles and sounds of

approval, “Oh Yeah” (line 371), “DA TA DA DA” (lines 372) and “We have a beautiful line” (line 399)!

Susan momentarily needed assistance in bringing up the data table display, “So how do we get that section thing” (lines 376-377)? John and Noliana answered together, “Window, Data Table” (lines 378-379). They all looked at the screen as the selections were made.

Discussion: Two things are noted in this dialog segment: the students continued to work cooperatively together with everyone participating, and they collectively took great pleasure in the fact that everything worked right. These students took delight in learning and had a good time in physics. They were happy when their data graphed as they expected—in a straight line with a positive slope. The pure joy of learning and having a project work out right were evident in their smiles and sounds of joy. The values of learning and taking pride in a job well done transcends physics; they apply to all of life. Many times students laugh in class at very inappropriate behavior of another person or they make fun of another individual. In this case students are enjoying the intellectual pursuit of learning.

There were several examples of collaboration and teamwork in this dialog. Each student looked at the computer screen and was involved in the manipulation of the software. John and Noliana helped Susan move between the Graph and Data Table display. Each person was involved in performing the experiment and evaluating the data. They communicated with each other and waited until each person was ready to perform

the experiment. Each person had a task to do to make the experiment work properly. Noliana held the cart for just the right moment of release. Susan manipulated the mouse and software to start and stop the data collection. She also marked invalid any questionable readings from the end of the experiment that had been recorded in the spreadsheet. She selected Graph, Point Protectors, and Regression Line from the series of choices under the Graph pull-down menu and watched as the velocity-time graph was drawn. John made sure that the string, mass, and pulley were set just right and caught the cart just as it hit the barrier.

The students continued their experiment and collected another set of acceptable data—the regression line though the data points had a positive slope. Susan saved both of these trial runs to disk. Noliana was eager to calculate the impulse and change in momentum of their first trial. In the dialog that follows, Noliana takes over the calculations as the group discusses which of the rows and columns of data should be used in the calculation.

- 444 Noliana: OK. Delta t. Let's
445 pick between five and one or
446 five and ten. Something like
447 that.
449 John: Do we want the shortest or
450 longest one?
452 Noliana: In his example up there,
453 he was like doing two and five so
454 why don't we do something like
455 five to one or ten to five?
457 Susan: We might want to do
458 something in the middle though
459 because that's what ...
461 John: Well, we are only covering
462 like two seconds though, so why

463 don't we do just the first data
 464 points and the last data points?
 466 Susan: What data points?
 468 Noliana: OK. So what is the last
 469 data point? Is the last data
 470 point good enough?
 472 Susan: [Susan went to the
 473 spreadsheet data table and put
 474 the mouse pointer next to the
 475 datum she wanted to use.] It's
 476 3.117.
 478 Noliana: That's the last data
 479 point?
 481 John: The last data point is t
 482 final.
 484 Noliana: What is it?
 486 Susan: 3.1173
 490 John: And t initial is
 491 2.5986.
 493 Noliana: OK. The mass of the
 494 cart we have. What is the delta
 495 v from the last and the first?
 497 Susan: OK. V initial is .3489.
 499 Noliana: Say it again.
 501 Susan: .3489 [Susan looked at the
 502 screen filled with multiple columns
 503 and rows of data.]
 505 Noliana: Un hunh.
 507 John: 1.7476
 509 Noliana: 1.7 what?
 511 John 1.7476.
 513 Noliana: OK. Equals ... TA DA.
 514 OK. 1.39 times ... OK [long
 515 period of silence.]
 516 OK, guys ... one is supposed to
 517 be negative, right? They are
 518 supposed to be equal and opposite
 519 to each other?
 523 [Noliana used a TI-82 calculator and
 524 calculated the impulse and change in momentum.]
 526 Susan: What?
 528 Noliana: Is one supposed to be
 529 negative?

531 Susan: I thought they were supposed
532 to be equal. What did we get?
534 Noliana: If one is supposed to be
535 negative they are close.
536 Susan: OK, one is supposed to be
537 negative. [She laughed.]
538 John: No, you reversed these.
540 [John pointed to the reversed
541 numbers on the sheet of paper
543 that Noliana recorded their work
544 on.]
551 Noliana: You reversed these?
553 John: Yeah. Because one is
554 suppose to be the initial and one
555 final.
557 Noliana: Oh, you told me them
558 backwards?
560 John: Yeah.
562 Noliana: Oh. Here you gave me
563 the final first.
565 Noliana: What's the initial
566 again?
568 John: .3489
570 Susan: For velocity? [Susan
571 looked at the spreadsheet of
572 numbers, the data table.]
574 John: Oh, velocity?
578 Susan: .9817
580 John: No. That is not the
586 beginning one. Go up. Go up.
587 Noliana: That's not right?
591 John: That's not right, it is
592 .3489.
594 Noliana: Oh, it is going to be
595 the exact same thing, except it
596 is going to be positive.
598 So, now we have 1.3987 times
599 .4862. So if it's positive,
600 the number72 equals .68.

Analysis: Noliana, the data recorder, calculated impulse and momentum from their first set of data they felt were good enough to save to disk. The computer produced many rows and columns of data; the students had to decide which data to use in their calculations. Noliana, "... Let's pick five and one or five and ten" (lines 444-446). Noliana noted that the teacher had modeled the calculation on the board, "In his example up there, he was like doing two to five so why don't we do something like five to one or ten to five" (lines 452-455)? John reasoned that the time for the force to act was so short they might as well use the first and last data points recorded. John, "Well we are only covering like two seconds though, so why don't we do just the first data points and the last data points" (lines 461-464)? Noliana wanted to make sure that the first and last values were valid, "Is the last data point good enough" (lines 469-4705)? John had perfected his technique of releasing and catching the cart, so he felt confident that the values were valid. Susan also thought the data were acceptable and responded to Noliana's concern by reading off the values from the Data Table, "It's 3.11" (lines 475-476).

Each member was involved in reading off the values for time, mass, and velocity. John, "The last data point is t_{final} " (lines 481-482). Noliana, "What is it" (line 484). Susan, "3.1173" (line 486). After Noliana worked the calculations, she questioned whether one was supposed to be positive and one negative. Noliana, "Is one supposed to be negative" (lines 528-529)? This dilemma set the group into a problem-solving or problem "cover-up" mode of action. Susan was willing to accept it even though she thought the impulse was supposed to equal the change in momentum (lines 537-538).

John looked back at the calculations, the values on paper, and the values in the data table. He discovered the error—the initial and final values were reversed in one of the calculations. John, “No, you reversed these” (line 543). Noliana also reasoned out in her mind what the problem was, “Oh, you told me them backwards” (lines 557-558). “Oh, Here you gave me the final first” (lines 562-563).

After they all agreed on the error, they all participated in selecting the values again and recalculating. They were more careful this time and caught each other’s mistakes before making the final calculations. Noliana, “What is the initial again” (lines 565-566). John made a mistake in calling out the value for the initial velocity which was caught by Susan. John, “.3489” (line 568). Susan, “For velocity” (570). John, “Oh, velocity” (line 574). When Susan called out the wrong number also, John and Noliana caught the error. John, “No. That is not the beginning one. Go up. Go up” (lines 580-586). Noliana too reacted, “That’s not right” (line 587). John called out the value, “... it is .3489” (lines 591-592). Noliana realized that the values were the same but the sign was different, “Oh, it is going to be the exact same thing, except it is going to be positive” (lines 594-596). Noliana calculated and recorded an impulse of .72 Newton seconds and a change in momentum of the cart of .68 kilogram meters per second (line 600).

Discussion: The dialog above illustrated how mathematics, science, and technology combine in the learning experiences of the students and how the students use the technology in problem solving. The computer dutifully collected hundreds of velocity and time data sets. The students had to determine which sets were best to use in their

calculations for this trial run. Noliana, John, and Susan made an initial mistake of transposing the initial and final values for time velocity. Consequently, they got a negative value for momentum and a positive value for impulse. This, too, was an example of problem-solving and data analysis. John was the first to discover that the values were transposed. Although students do have the opportunity to question data without technology, the computer and Smart Pulley enabled the students to do this in a timely manner.

The students analyzed data sets within minutes of conducting the experiment because of the ability of the computer to quickly calculate variables such as velocity and acceleration based on time and distance input, to organize data into data tables, and to display the data graphically. This laboratory experiment could not have been conducted in a traditional physics classroom, as explained above, because time measurements could not be made with sufficient accuracy.

In addition, experiments in which the students make time and distance measurements and then calculate velocity, acceleration, and other quantities take hours to perform the calculations, to construct data tables, to graph, to draw the best fit line, and to analyze the relationship represented by the graph. Due to time constraints within class periods and the time that it takes to collect data in traditional ways, the number of trial runs and data sets the students are able to collect are restricted. Students sometimes find that the data they collected are flawed and the experiment has to be done again which means they must return after school. The teacher therefore, must keep the equipment in

the room for several days after the lab experiment is conducted, in order to accommodate those students who need to redo their experiment. The computer's data collection and processing abilities have greatly reduced the time that students and teachers spend in redoing experiments while increasing the number of data sets that the students collect and analyze.

The students in this dialog evaluated their data and accepted the values as “good” based on the slope of the regression line that appeared on the computer screen shortly after they completed their experiment. Within minutes of conducting the experiment, they were ready to complete their calculation of impulse and momentum and compare those values. In traditional lab settings, all too often one lab partner takes the data home and calculates the values without input from the others in the lab group. In this case, everyone was involved in the calculations and could think through the source of error—transposed time readings—together.

One of the purposes of the lab was to compare the impulse (force times change in time) caused by the falling mass and taut string with the change in momentum (mass times change in velocity) of the cart. The students completed several trial runs within the period and saved three data sets to use in their lab report. They reported the two best trials in their final written lab report, one with a 5.71 percent error (variance) and one with a 4.07 percent error (variance). The students were proud of their results and reported in their lab report, “The percent errors were not zero but they were all below 10 We ran three

trials for each equation and used the best two so we think this is good data considering the sources of error (friction).”

Many times in traditional physics labs the experimental error is so great that the students have to accept the relationship based on “faith.” This technology—computers, Smart Pulleys, dynamics carts, and software—allowed the students to better understand the impulse-momentum and work-kinetic energy relationships because their variances were low. In their *Smart Pulley Lab Write-up* [lab report] (May 1, 1995), John, Noliana, and Susan wrote, “The equations did not exactly equal, but they are close and the percent errors are small so we can say that the equations were close enough to be considered equal” (p. 2).

One last dialog segment from this groups’ April 28 laboratory experiment is presented below to illustrate how the teacher is able to capture teachable moments more readily when computer technology is present. In this case, the student did not know how to find the percentage error (variance) between the impulse and the change in momentum of their trials. Most of the students in this class were seniors and many have had several classes in mathematics including trigonometry-math analysis; some were concurrently enrolled in calculus. However, they still had problems in calculating percent error. Noliana was the first of several students who was taught individually by the teacher at the board. The following dialog was taken from the audio recording of the stationary camera’s remote microphone which was attached to the teacher’s lapel. (file p2428.eth).

Noliana had just finished the impulse and momentum calculations of the first trial run and she went to get help from the teacher because of her and her lab partner's confusion about how to find percent error (variance). She walked over to the teacher who was working with another group of students on the other side of the room. She waited until the teacher finished and could help her.

- 2057 Noliana: OK. We did this lab and
2058 we got .720 equal .680. Is that
2059 close enough?
2061 T: How would you determine the
2062 difference there?
2064 Noliana: What do you mean? Oh,
2065 what would be the reason why it
2065 would be different?
2068 T: No, How would you quantify
2069 the error?
2071 Noliana: It's 4 percent error.
2072 It would be 4 off, .4 off ...
2073 which is 4 percent.
2075 T: I don't think the
2076 difference is 4 percent.
2078 Noliana: It would be .04 off.
2080 T: Come up here. [They walked to board.]
2081 What if you had two numbers,
2082 100.36 and 100.40. You had two
2083 trials, trial one and trial two.
2085 Noliana: The difference is .04

The teacher explained that the difference is .04 but since there is no theoretical value, .04 must be divided by the average of the two trial values.

- 2123 T: In other words, .04 divided by
2124 .70. Isn't that the average of
2125 your two values?
2127 Noliana: Oh, yeah.

Analysis: Noliana questioned whether the data were acceptable and how to find percent error (variance). Noliana's first question was "... we got .720 equals .680. Is that close enough" (lines 2058-2059)? Prior to asking the teacher, she and her lab partners had a brief discussion about percent error (variance). They knew the error (variance) was low. They thought that it was 4%, but they were not sure. All of them talked about errors of 100% and over in some of their chemistry lab experiments.

Noliana knew that the difference was .04 but she did not know how to find the percent error (variance). She made a common mistake of students in assuming that .04 is a 4% error (lines 2071-2072). The teacher took her to the board and explained how to find percent error (variance) when neither value is the "true or theoretical" value. The teacher, "In other words, .04 divided by .70. Isn't that the average of your two values" (lines 2123-215)? Most probably, Noliana did similar calculations in her previous chemistry class but she did not remember, "Oh, yeah" (line 2127). She seemed to recognize the method and the "Oh, yeah," was more of an acknowledgment that she had used this formula before.

Discussion: The teachable moment was created because the teacher was able to respond to the individual student's need. All students in the room were actively engaged in learning in groups at the computers; so the teacher could work with one individual to reinforce the mathematical method of finding percent error. Noliana used a graphing calculator but she didn't understand or remember how to perform percent error

calculations. The teacher is an indispensable component in learning and in the use of instructional technology.

In conclusion, these dialog segments from the Smart Pulley probeware experiment on the conservation of momentum and energy have illustrated:

- Experiments can be performed that were impossible to do with traditional apparatus.
- Calculator and computer technology are tools in the learning process which enable students to collect and graphically display multiple data sets.
- Students enjoy the learning process and take pride in written laboratory reports that are done on the computer.
- The role of the teacher is one of master planner, facilitator, reinforcer of learning, and monitor of student progress.
- The use of the computer technology provides teachable moments.
- The combination of computer technology and cooperative learning teaching strategies combine to make a powerful learning experience for students.
- Students have ample experience in problem-solving when computer technology is used.

The computer enabled students to perform an experiment that was impossible to do otherwise. Conservation laws are fundamental concepts in physics and are difficult for students to understand. The technology allowed students to compare impulse with change in momentum and change in kinetic energy with work on a system.

The computer and calculator were technology tools in the learning process. The computer, *ULI Timer* software, ULI, and Smart Pulley probe collected time and distance data and displayed the data in usable formats: a spreadsheet data table and a graph. The computer manipulated the raw data to calculate velocity and acceleration; mathematical operations that would have taken the students hours to do by hand. Student learning was enhanced by the speed of the display of the data in a graphical format immediately after the experiment was performed. The TI-82 calculator also was a tool in the learning process and greatly increased the speed of mathematical calculations.

The computer enabled the students to produce a final written lab report of which they were proud. The lab report was word processed and included spreadsheet data tables, statistical analysis of data, and computer-generated mathematical symbols.

The dialog series also illustrated the roles of the students and the teacher when computer-related technology is present. The students worked in cooperative groups and learned from each other as they used the technology. They shared knowledge with each other about how the software and hardware worked and about physics concepts and calculations. They checked each other's work and openly communicated within their groups in verbal, non-verbal, and written forms of communication. All students, including the girls, actively participated in the learning process.

The role of the teacher was different from his role in the traditional classroom. The teacher was the master planner or facilitator, reinforcer of learning, and monitor of student progress. He planned whole units of study and provided for student learning by using a

variety of resources—simulation and utility software, probeware, videotapes, problem sets, readings, and tests. These dialog segments illustrate his interactive role in the classroom when probeware was used. He monitored groups, and went to individual groups when he was called or he noticed that the group needed assistance. He took advantage of teachable moments by working with individuals or small groups of students. The teacher remains a vital part of the learning process in a technology-rich classroom.

Summary of Examples From the Technology-Rich Classroom

In summary, the four examples of classroom dialogs illustrate the changing role of the students and the teacher and illustrate some of the unique learning opportunities that are made possible through the use of computer-related technology.

The student's role.

The researcher found that students were actively engaged in their own learning. The conversations of the students were almost entirely on the task at hand—the learning of physics concepts. Rarely and for only a few moments were conversations about the daily routines or after school interests of students such as the weekend activities or the Prom. Student conversations were about the learning taking place in which they were directly and actively involved. They discussed the experiment, the calculations, and the physics concepts.

The combination of technology and cooperative learning strategies combined to make a powerful learning experience for students. The students' conversations and actions evidenced that they learned from each other and from the technology with varying degrees

of guidance from the teacher. Frequently, when confronted by a question or problem to solve, the students used this common routine: (1) discuss and clarify the problem within the group (2) ask neighboring group or groups for possible solutions and (3) ask the teacher if no peers seem to understand how to solve the problem. Frequently, in his process of monitoring student progress, the teacher realized that a group was having difficulty and he would approach them before they asked. If the teacher did not first intervene during the problem-solving process, the students would either call out for help or physically move to where the teacher was to directly ask for assistance. Students learned the process of problem-solving and worked collaboratively as they learned from each other.

The computer and videotape technology enabled the students to work cooperatively in small groups and to learn from each other as they discussed the video, the simulation experiment, or the laboratory experiment. The size and interaction of the group varied with the activity. They worked in groups of two to three students on the computer simulations and laboratory experiments and in groups of three to four on group quizzes based on the *Mechanical Universe High School Adaptation* video tapes. Students worked in groups of two to four on homework problem sets. Although experiments, simulations, and videotape quizzes were done collaboratively, the three or four major tests per semester were taken individually.

The students enjoyed the process of learning and took pride in the documents they produced using the computer. Frequently sounds of delight for a solved problem or a

graph that “turned-out right” would be heard in the class. The students would cheer or make comments such as “We got it!”, “Look at that beautiful line!” They always turned in word processed lab reports with imbedded data tables and computer-generated graphs with a statistical analysis of the data. The pride in their work was evidenced in the alternative assessment HyperCard Stacks that were created by the Physics 1 GT class. The students not only explained the concepts and facts about circular motion, they added sound and creative artistic illustrations. One group took a clip art picture of the Statue of Liberty and drew in a ball on a string extended from her raised hand. They added motion to the illustration by having the ball move in a circular orbit as they explained the mathematical formulas for circular motion on the voice track.

The students not only took pride in their written documents, they took pride in and maintained the computer technology that was in the room. In order to keep the hard drives free of student work, they saved data and documents to their own disks . Although the students word processed their reports, they made all of the corrections by reading the computer screen and making changes prior to printing. The students sparingly used the laser printer to make the final copy of all documents, thus cutting down on the expense of paper and toner associated with laser printers. All of these efforts by the students made the computer classroom more usable by all students and kept the computers functioning most of the time.

The teacher's role.

The computer technology provided many teachable moments. Once the student groups were actively engaged in their own learning, the teacher could devote more time to individuals. He monitored student progress and frequently worked directly with a student or a lab group, leading them through a problem-solving strategy either at the computer or on the board. He frequently took a student or small group of students to the board to work through mathematical problems. He knew the software programs well and often called out direct computer commands to the students when they encountered problems such as how to insert a formula into a spreadsheet cell. He knew how the probeware worked and occasionally worked with students who had difficulty in getting the probeware to work properly. He and the students, together, evaluated data. The teacher and the students took advantage of the teachable moments that the computer provided.

The teacher's roles of planning technology-based laboratory experiences and of using effective teaching and assessment strategies were complex. The teacher became a facilitator, a monitor of student progress, and a help to the individual(s) most in need of help. In his role as facilitator, the teacher prepared his classroom for student learning using the technology. See Figure 5 for a diagram of the classroom. The teacher set up his lab so that all student computer screens could be easily seen from the center and front of the room, enabling him to monitor student progress. At the beginning of the class period, the teacher took a position at the front of the room as he engaged students in whole-class discussions. After he directed students to begin lab experiments or simulations, he left his

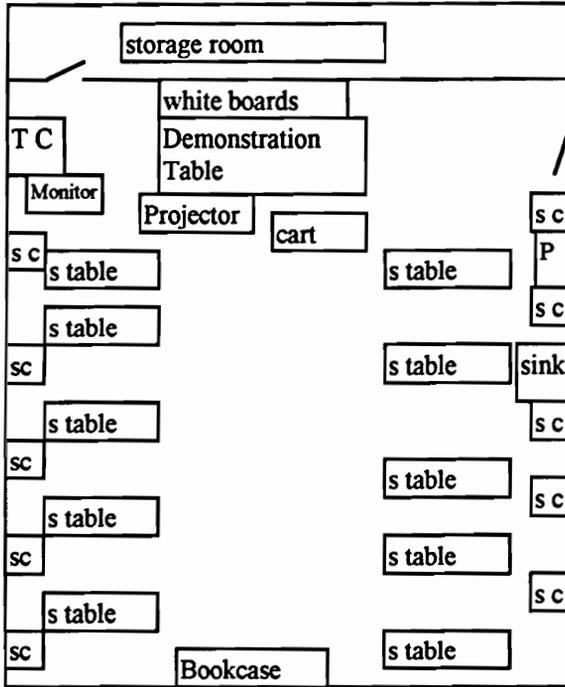


Figure 5. Diagram of physics classroom. P= laser printer, s table = student lab table, s c = student computer, TC = teacher computer, cart = equipment and supply cart, and Monitor = cart with TV/monitor, VCR, and videodisc player.

position at the front of the room and walked up and down the central aisle assisting individuals or groups.

The use of computers caused the teacher to change the student handouts and other papers used in the classroom as well as the organization of these curriculum materials. The teacher created word-processed student handouts for each teacher-generated laboratory experiment or project. These teacher-made directions and the commercially-produced student materials were organized in unit file folders for ease of student use in the classroom. Instead of a handout for each physics student, a class set of handouts was copied and filed. At the beginning of the period, a student obtained copies of the materials for his lab group and returned the copies to the proper folders at the end of the period. Students soon learned the routine and became independent of the teacher as they worked through the different laboratory activities.

The teacher planned units with multiple activities, several of which were taking place in the room at one time. Equipment, supplies, and handouts were available for each activity. Equipment and supplies were on the cart and handouts were in the folders on the demonstration table. This system of organization allowed students to get handouts, supplies, and equipment as they worked through the experiments, simulations, and other activities.

Another management or classroom organizational change due to computer technology was noted in the way in which students kept information. Not only did they maintain notebooks, they kept disks with data and laboratory reports. These disks were

kept in the classroom in two large disk-storage boxes at the back of the room. Each student had a disk and one member of the group retrieved a disk at the beginning of the experiment. Usually the group only used one person's disk but occasionally they saved data on more than one disk. The HyperCard assessment activity was kept on disks and the students turned in the final product on disk. The teacher and the students adjusted to the use of this new technology with alternative ways of maintaining, storing, and disseminating information.

New and unique learning opportunities.

The computers enabled the student to conduct lab experiments that were not possible in traditional classrooms. The probes allowed students to graph data in real-time or immediately after data were collected. During the kinematics unit, the students studied motion with the use of motion detectors that graphed the movement of their own bodies as well as carts in real-time. Data were displayed in three graphs: the distance-time, velocity-time, and acceleration-time. In the study of conservation of momentum and energy, the Smart Pulley and photogates enabled students to conduct experiments that measured time more precisely than could be done with stopwatches, thus enabling students to perform experiments that could not be done in traditional physics classrooms.

Two of these new laboratory experiments were studied in detail, *Impulse and Momentum Lab* and the *Smart Pulley Lab on Impulse, Momentum, Work, and Energy*. They provided evidence for the computer's ability to collect multiple data sets in a short period of time. The students became critical thinkers as they evaluated their data for

validity. With the immediate feedback from the computer, the students frequently chose to redo a trial after they discovered and corrected problems in their apparatus or with invalid data sets. They examined data displayed in several formats—raw data, data tables and graphs. The students manipulated the software to produce graphs with properly defined axes, correct data ranges, correct units, and appropriate titles. They also learned the meaning of error bars and regression lines. Since the computers took the drudgery out of graphing large data sets, the students tended to collect more data as a part of each experiment and to interpret the statistical information that the software provided.

In addition to using computers, students used the Texas Instrument's TI-83 or TI-82 graphing calculators (TI-83 and TI-82) to aid in calculations and display of data. Although the students used their calculators in math class as well as science, the teacher spent many minutes explaining how to enter data and perform calculations on the calculator. Not all students in the physics classes were in the most advanced math classes. Learning to use this technology enabled them to concentrate on the concepts instead of doing the arithmetic by hand. As a result of the use of calculators in physics, the lessons students learned in mathematics were reinforced.

Analysis of the Force Concept Inventory

After the presentation of the initial Prospectus, it was recommended that a quantitative piece be added to the research of students' learning in physics with technology. The *Force Concept Inventory* (FCI) was administered to the students toward the end of the school year. The FCI is nationally recognized by physics teachers. The

results and comparisons of the students in this study with the Arizona students in the Hestenes et al. study are discussed below (see Appendix E for a complete copy of the *Force Concept Inventory*). However, no strong conclusions are drawn from the results of the students in this study on the FCI.

The Force Concept Inventory has been widely used by high school and college physics teachers since its publication in *The Physics Teacher* in 1992. The FCI was designed to probe students commonly held beliefs about the mechanical world compared with Newtonian concepts. The twenty-nine question inventory is limited to the measurement of student understanding of force concepts in six areas—kinematics, first law, second law, third law, superposition principle, and kinds of force (Table 5). Thirty misconceptions said to be addressed by the inventory were examined (Table 6).

The responses of twenty one students in the regular Physics 1 class and twenty seven students in the gifted and talented Physics 1 GT class in this study were compared with the responses of six hundred twelve Arizona regular physics students and one hundred eighteen honors students in the Hestenes et al. study. Approximately fifty eight percent of graduates from the school in this study take high school physics compared with nineteen to twenty three percent nationwide; the percentage of graduates who take physics in the Arizona schools in the Hestenes study is not known.

Only the post test was administered to the students in the study group. Hestenes et al. found "pretest scores are so uniformly low for beginning physics students that further pretests are really unnecessary ..." (p. 150).

The two classes in this study were given no prior warning that an inventory would be administered. They were not prepared in any way and the inventory was given several weeks after the study of mechanics was completed. Students were studying electricity and magnetism at the time of the evaluation. The teacher in the study had no previous knowledge of the inventory and taught in his usual manner without a conscious effort to address misconceptions in physics any more or less than he had in past years. The inventory was administered by a substitute teacher while the teacher was out of the country for a week. There was no time limit placed on the students, in keeping with the conditions described by Hestenes et al. in the Arizona testing.

Although the N of students (21 regular students and 26 GT students) in this study was too low to be statistically significant, some general comments are made concerning the responses selected by students. In an examination of the Newtonian Concepts (Table 5), students in this study did relatively well on most questions relating to Newton's first law, Newton's third law, and the idea that acceleration is independent of weight. The results of the regular and gifted and talented (GT) students in the study were compared with the regular and honors Arizona students on the six Newtonian concepts and the thirty misconceptions. (See Tables 5 and 6.)

Kinematics

Six questions—20,21,23,24,25, and 7—addressed kinematics concepts. Three misconceptions were examined: position-velocity discriminated, velocity-acceleration discriminated, and nonvectorial velocity composition. In general, the Arizona regular and

honors students did slightly better on kinematics concepts than did the regular and GT students in the study. Neither group scored particularly well since most Newtonian kinematics concepts were correctly identified only about 31% of the time. The Arizona regular students did better on interpretation of a graph in question 20 which dealt with the discrimination between velocity and position of two blocks. The common misconceptions were velocity is proportional to applied force and velocity-position undiscriminated, and velocity-acceleration undiscriminated.

First Law

Newton's first law is based on Galileo's principle of inertia: every body continues in a state of rest or in straight line motion at a constant speed, unless acted on by a force. Newton's first law was examined in eight questions—4,6,10,26,8,27,18, and 28. The students in the study did slightly better or about the same on most of the Newtonian first law questions. Two of these questions, 8 and 4, were examined in detail.

In question 8, "Along the frictionless path you have chosen, how does the speed of the puck vary after receiving the 'kick'?" Sixty two percent of the regular students and 81% of the students in GT physics in this study correctly answered, "no change"; while 53% of the Arizona regular students and 64% of the Arizona honors students answered correctly.

Question 4 also addressed Newton's first law, a ball on a string is rotated in a horizontal plane and released. Sixty two percent of the regular students and 95% of the GT students in this study and 72% of the Arizona regular students and 62% of the

Table 5

Newtonian Concepts on the Force Concepts Inventory

Newtonian Concept	Item Description	Item	AZ Reg	AZ Honors	Study Reg	Study GT
			n = 612	n = 118	n = 21	n = 27
Kinematics			% of students with the correct answer			
Velocity discrimination from position	interpretation of graph two blocks—speed	20E	38	48	10	30
Acceleration discriminated from velocity	interpretation of graph two blocks—acceleration	21D	37	50	24	44
Constant acceleration entails:						
parabolic orbit	ball's path after drop from plane	23D	47	59	24	48
parabolic orbit	rocket's path after thrust	24E	22	41	10	26
changing speed	rocket's speed after thrust	25D	38	56	19	56
Vector Addition of velocities	puck speed after kick	7E	33	46	19	33
First Law						
With no force	ball's path after release from circular orbit	4B	72	66	62	92
With no force	hockey puck's path after kick	6B	58	63	38	59
With no force	ball's path after circular channel	10B	88	91	62	85
velocity direction constant	rocket's path after engine is off	26B	42	48	40	41
speed constant	puck's speed after kick	8A	53	64	62	81
speed constant	rocket's speed after engine is off	27A	77	84	45	85
With cancelling forces	elevator lifted with constant velocity	18B	25	32	33	11
With cancelling forces	box pushed with constant speed	28C	28	39	20	19
Second Law						
Impulsive force	hockey puck's path after kick	6B	58	63	38	59
Impulsive force	hockey puck's velocity after kick	7E	33	46	19	33
Constant force implies constant acceleration	rocket's path after thrust	24E	22	41	10	26
Constant force implies constant acceleration	rocket's velocity after thrust	25B	38	56	19	56
Third Law						
For impulsive forces	car-truck collision	2E	33	37	60	59
For impulsive forces	student-student push	11E	33	45	48	48
For continuous forces	car pushes truck force during acceleration	13A	19	23	57	33
For continuous forces	car pushed truck force after constant speed	14A	64	68	52	56
Superposition Principle						
Vector sum	box's path with two forces	19B	74	77	52	85
Cancelling forces	puck's forces after kick (air table assumed)	9D	30	30	5	26
Cancelling forces	elevator lifted with constant velocity	18B	25	32	33	11
Cancelling forces	box pushed with constant speed	28C	28	39	20	19
Kinds of Force						
Solid contact passive	puck's forces after kick (air table assumed)	9D	30	30	5	26
Solid contact passive	forces on book on table	12B,D	84	87	57	89
Solid contact impulsive	rubber ball-floor, why direction change	15C	39	36	38	41
Solid contact friction opposes motion	action after force to box is stopped	29C	59	60	35	37
Fluid contact air resistance	forces acting after golf ball is hit	22D	30	29	5	22
Fluid contact buoyant (air pressure)	forces on book on table (air pressure)	12D	0	0	5	0
Gravitation	forces on ball in air	5D	30	26	24	22
Gravitation	puck's forces after kick (air table assumed)	9D	30	30	5	26
Gravitation	forces on book on table	12B,D	84	87	57	89
Gravitation	stone falling, reason for increased speed	17C	60	66	52	70
Gravitation	elevator lifted with constant velocity	18B	25	32	33	11
Gravitation	forces acting after golf ball is hit	22D	30	29	5	22
Acceleration independent of weight	2 balls unequal mass drop	1C	75	80	95	96
Acceleration independent of weight	2 balls unequal mass roll off table	3A	35	57	52	59
Parabolic trajectory	path of cannon ball shot from building	16B	67	83	57	70
Parabolic trajectory	ball's path after drop from plane	23D	47	59	24	48

Note. Table 5 is based on Table I. Newtonian Concepts in the Inventory (Hestenes, Wells, and Swackhamer, 1992, p. 142). Arizona regular and honors data were interrupted from Table V. Force Concept Inventory Item Interpretation and Response Frequencies for Six Student Populations (pp. 152-153).

Table 6

Misconceptions

Misconception	Description	Item Response	AZ Reg % Error	AZ Hon % Error	Study Reg % Error	Study GT % Error
Kinematics			n=612	n=118	n=21	n=27
K1	position-velocity discriminated	20 B,C,D	40	37	62	37
K2	velocity-acceleration undiscriminated	20 A	23	15	29	33
		21 B,C	37	24	19	29
K3	nonvectorial velocity composition	7 C	25	22	24	26
Impetus						
I1	impetus supplied by "hit"	9 B,C	66	64	81	65
		22 B,C,E	65	70	91	71
		29 D	2	1	0	0
I2	loss/recovery of original impetus	4 D	3	0	10	0
		6 C,E	13	7	5	11
		24 A	4	4	10	7
I3	impetus dissipation	26 A,D,E	26	26	45	26
		5 A,B,C	68	74	61	78
		8 C	20	15	15	7
		16 C,D	32	16	39	26
I4	gradual/delayed impetus buildup	23 E	0	1	0	0
		27 C,E	19	11	35	15
		29 B	15	10	25	22
		6 D	13	7	5	11
I5	circular impetus	8 B,D	20	15	15	7
		24 D	4	4	10	7
		29 E	15	10	25	22
		4 A,D	7	1	20	4
		10 A	9	4	24	4
Active Force						
AF1	only active agents exert forces	11 B	8	5	5	4
		13 D	2	0	5	0
		14 D	2	3	10	4
		15 A,B	43	54	43	37
		18 D	6	5	5	0
		22 A	6	2	5	7
AF2	motion implies active force	29 A	24	29	40	41
AF3	no motion implies no force	12 E	1	2	5	0
AF4	velocity proportional to applied force	25 A	32	20	57	15
		28 A	14	15	25	15
AF5	acceleration implies increasing force	17 B	18	14	24	15
AF6	force causes acceleration to terminal velocity	17 A	16	11	10	7
		25 D	20	17	19	30
AF7	active force wears out	25 C,E	9	33	5	0

Table 6

Misconceptions (Continued)

Misconception		Item Response	AZ Reg % Error	AZ Hon % Error	Study Reg % Error	Study GT % Error
Action/Reaction Pairs			n=612	n=118	n=21	n=27
AR1	greater mass implies greater force	2 A,D	66	60	30	41
		11 D	63	48	38	44
		13 B	9	7	5	11
		14 B	3	1	14	4
AR2	most active agent produces greatest force	13 C	69	70	33	66
		11 D	63	48	38	44
		14 C	27	28	24	33
Concatenation of Influences						
CI1	largest force determines motion	18 A,E	78	61	62	89
		19 A	2	2	0	0
CI2	force compromise determines motion	4 C	6	14	5	0
		10 D	1	3	10	4
		16 A	1	1	5	0
		19 C,D	24	21	48	15
		23 C	11	6	10	4
CI3	last force to act determines motion	24 C	28	17	33	30
		6 A	25	4	48	30
		7 B	28	18	48	22
		24 B	20	21	38	22
		26 C	32	26	15	33
Other Influences on Motion						
Centrifugal force						
CF	centrifugal force	4 C,D,E	24	33	29	4
		10 C,D,E	4	6	15	11
Obstacles						
Ob	obstacles exert no force	2C	0	0	5	0
		9 A,B	19	22	47	9
		12 A	5	5	19	4
		13 E	0	0	0	0
		14 E	3	1	0	4
Resistance						
R1	mass makes things stop	29 A,B	39	39	65	63
		23 A,B	41	34	67	48
R2	motion when force overcomes resistance	28 B,D	65	45	50	63
R3	resistance opposes force/impetus	28 E	3	1	5	4

Table 6

Misconceptions (Continued)

Misconception		Item Response	AZ Reg % Error	AZ Hon % Error	Study Reg % Error	Study GT % Error
Gravity			n=612	n=118	n=21	n=27
G1	air pressure assisted gravity	9 A	3	4	14	0
		12 C	11	13	19	7
		17 E	6	8	10	0
		18 E	15	4	29	0
G2	gravity intrinsic to mass	5 E	1	0	5	0
		9 E	0	2	0	0
		17 D	2	1	5	4
G3	heavier objects fall faster	1 A	7	6	4	0
		3 B,D	67	40	48	30
G4	gravity increases as objects fall	5 B	14	16	19	19
			18	14	24	15
G5	gravity acts after impetus wears down	5 B	14	16	19	19
		16 D	0	0	0	0
		23 E	0	1	0	0

Note. Table 6 was based on Table II. A Taxonomy of Misconception Probed by the Inventory (Hestenes, et al., 1992, p. 144). Arizona regular and honors data were interpreted from Table V. Force concept Inventory Item Interpretation and Response Frequencies for Six Student Populations (pp. 152-153).

Arizona honors students correctly selected the path tangent to the circle as the path the ball would follow when released.

Second Law

Newton's second law, commonly written as $F=ma$, states that more massive objects require more net force for the same acceleration. Another way to say it is that the acceleration of an object is directly proportional to and in the same direction as the net force and inversely proportional to the mass. Questions 6,7, 24, and 25 were designed to

check student understanding of Newton's second law, often called Newton's law of motion. About 20% of the regular and honors Arizona students and 20% of the GT and 38% of regular study students seemed to have the misconception that the last force to act determines motion. Questions 6 and 7 examined the path and speed of a hockey puck after receiving a kick. Students had to add vectors to predict the path and the speed. More students missed question 7, "The speed of the puck just after it receives the "kick" is ... greater than either of speeds ' v_0 ' or ' v ' but smaller than the arithmetic sum of these two speeds." Nineteen percent of the regular students in the study and 33% of the GT students in the study answered the question correctly compared with 33% of the Arizona regular students and 46% of the Arizona honors students.

Third Law

Newton's third law states that whenever a body exerts a force on a second body, the second body exerts an equal and opposite force on the first body. Newton's third law of equal and opposite forces was addressed in questions 2, 11, 13, and 14. Students in the study did better on three of the four questions than did the Arizona students. In question 2, 60% of the regular students in this study and 59% of the GT students answered that in a head-on collision between a truck and a small compact car, "the truck exerts the same amount of force on the car as the car exerts on the truck." Only 33% of the Arizona regular and 37% of the Arizona honors students answered the question correctly. The most common misconception from all groups of students on Newton's third law was that the most active agent produces the greatest force.

Superposition Principle

Questions 19, 9, 18, and 28 examined vector sums of forces and canceling forces. The two most common errors on these questions were impetus is supplied by “hit” and largest force determines motion. Most students correctly predicted the path that a box would take with two forces acting on it—the box was being pulled by a man and a young boy. Fifty-two percent of the regular students and 85% of the GT students correctly answered the question compared to 74% of the regular Arizona students and 77% of the honors students. However, most students missed the questions about canceling forces. In question 18, students were asked about the forces acting on an elevator that is moving at a constant velocity. Only 33 % of the regular students and 11 % of the GT students correctly answered that the upward force acting on the elevator by the cable is equal to the downward force of gravity. Twenty five percent of the Arizona regular and 32 % of the honors students correctly answered the question. Most students thought that the upward force of the cable was greater than the downward force of gravity.

Kinds of Force

Twelve questions were categorized as kinds of forces—1, 3, 5, 9, 12, 15, 16, 17, 18, 22, 23, and 29. Questions 9, 12, 15, and 29 asked about forces when there was solid contact. Questions 12 and 22 examined fluid contact. Questions 5,9, 12, 17, 18, and 22 were about gravitation. Question 1 and 3 looked at the independence of acceleration and weight and questions 16 and 23 examined parabolic trajectory.

Solid contact question 9 asked about forces acting after a ball is kicked. Question 12 asked about forces acting on a book on a table. Question 15 asked about the forces acting on the ball that hits the floor and rebounds. Question 29 asked about the motion of a box when the force being applied is suddenly discontinued. In general, the regular students in the study scored lower than the regular Arizona students on these questions. The GT students scored about the same as the Arizona honors students.

Fluid contact was examined in questions 22 and 12. Virtually no one (5% regular , 0% GT, 0% Arizona regular, and 0% Arizona honors) answered question 12 correctly by including the buoyancy of air as a force acting on a book on a table. More students in the study missed question 22, which asked about the forces acting on a golf ball after it is hit. Only 5 % of the regular and 22% of the GT correctly answered the force of gravity and the force of air resistance acted on the ball as compared with 30 % of regular Arizona students and 29% of honors Arizona students. Most of the students thought that the force of the hit as well as the forces of gravity and air resistance acted on the ball after the hit (86% of study regular, 56% of study GT, 56% of Arizona regular, and 62% of Arizona honors).

Students in the study did better on the gravity-related misconception that heavier objects fall faster (see questions 1 and 3, Table 6). Question 1 asked how long it will take for balls of different masses to fall from the top of a two story building. Ninety-five percent of the regular physics students and 96% of the GT physics students answered correctly, "C. about the same time for both balls." Seventy-five percent of the Arizona

regular students and 80% of the honors students answered question 1 correctly. Question 3 asked students where two balls of unequal masses would impact on the floor if they left a table at the same time. Fifty two percent of the regular students and 59% of the GT students in this study answered correctly that “both balls impact the floor at approximately the same horizontal distance from the base of the table.” Only 32% of the Arizona regular students and 57 % of the Arizona honor students answered correctly.

Parabolic trajectory was examined in two questions, question 16 and question 23, and in both questions the Arizona students selected the correct trajectory path more frequently than did the students in the study. Fifty two percent of the regular students and 70% of the GT students in the study correctly predicted the parabolic path of a cannon ball being shot from a cannon compared to 67% of the regular students and 83 % of the Arizona honors students correctly predicting the path. Both groups did slightly worse on predicting the path of a bowling ball being dropped from a plane but, again, the Arizona students were better able to predict the path of the ball than were the students in the study group.

Questions of Validity of FCI

While the FCI has been widely used, some physics educators have questioned the validity of the *Force Concept Inventory*. Huffman and Heller (1995) question, “What Does the Force Concept Inventory Actually Measure?” (p. 138). After completing a factor analysis, they found that, “Items on the inventory appear to be only loosely related to each

other, and instructors should be cautious about concluding that the inventory actually measures students' understanding of a 'force concept'" (p. 141).

However, Huffman and Heller acknowledge that the twenty-nine multiple choice inventory does provide, "An informative look at students' non-Newtonian views of physics" (p. 138). The researcher and the teacher in the study believe that the inventory can be used to change teaching strategies that will address misconceptions in physics.

In order for the reader to interpret the results, background information on the Hestenes et al. study is briefly described. Teachers in the Hestenes et al. study participated in a six-week workshop, funded by the National Science Foundation, in which teachers learned to apply teaching methods thought to be useful in overcoming students' misconceptions in physics. "The method is computer-based and laboratory-oriented instruction with no lectures, but with much class discussion and some special techniques to stimulate it" (p 147). Computers were used to collect data in both the Hestenes et al. study and in this study.

The Arizona teachers in the Hestenes et al. study indicated that, "... they were so involved with the mechanics of the method—computers, lab activities, discussion technique—that they failed to fully appreciate the crucial pedagogical core that makes it effective. The net result is another demonstration that technology by itself cannot improve instruction. The best that technology can do is enhance the effectiveness of good pedagogy" (p 147).

The time needed for teachers to make major changes in their instruction is more than one year (Becker, 1992; Dwyer, et al., 1990a, 1990b; Hadley & Sheingold, 1993; Sheingold & Hadley, 1990). While pedagogy is important, understanding change is also important. Teachers take three to seven years to effectively incorporate new technology into their teaching repertoire. Sheingold and Hadley found that it takes five to six years for expertise in computer use to develop among teachers. Becker's survey revealed that exemplary users had an average of four years of computer experience. Hestenes et al. apparently expected these teachers to make major changes in one year after an "intensive" workshop.

The results of the FCI must be interpreted in the context of other evidence of student understanding. The researcher questioned the validity of the assessment of student misconceptions since their responses did not consistently illustrate a misconception. This point will be more fully developed below. In addition, there are confounding variables in the instrument design that are questioned such as assumptions about students' experience with laboratory apparatus. For example, in question 9, student knowledge of an airtable and puck is assumed. While there is no mention of an airtable in the main body of the question and no illustration of an airtable accompanies the question, the correct response assumes an airtable is present. A second design flaw that was noted is the placement of two similar diagrams for questions 20 and 21 (see Appendix F). The block position-time diagram that corresponds to question 20 is located on the page preceding the question

while a similar block position-time diagram is located between questions 20 and 21.

Students could easily confuse which of the two diagrams is associated with question 20.

Inconsistency of students responses on the same misconception were noted on several misconceptions listed in Table 6. One of the most glaring differences was found in questions 9, 22, and 29 that tested for the misconception “impetus supplied by ‘hit’” (see Table 7 for the list of these questions). Students did not view these questions as examining the same misconception. Few students (0% to 2%) missed question 29 but most missed question 22 (65% to 91%) and question 9 (64% to 81%) . Question 9 and question 22 asked about the forces acting on objects after a hit. Question 29 asked what would happen to the speed of a box being pushed across the floor if the force is suddenly discontinued. Almost no one selected item response 29D, “continues at a constant velocity,” designed to test for the misconception. Since so many students missed question 9 and 22, they were examined for confounding variables.

In question 9, students are asked about the force(s) acting on a puck after a kick. As discussed above, student experience with an airtable is assumed in the question, since the correct response includes the upward force exerted by the table. However the researcher doubts that many teachers have an airtable; the teacher in this study did not have an airtable. Most students missed this question, 70% of the Arizona regular students, 70% of the Arizona honors students, 95% of the regular students in this study, and 74% of the gifted students in this study. The “misconception impetus supplied by the hit” cannot be interpreted as the reason for students missing this question.

Table 7

Selected Questions from the Force Concept Inventory

Question 9: The main forces acting, **after** the “kick” on the puck along the path you have chosen are:

- (A) the downward force due to gravity and the effect of air pressure.
- (B) the downward force of gravity and the horizontal force of momentum **in the direction of motion.**
- (C) the downward force of gravity, the upward force exerted by the table, and a horizontal force acting on the puck **in the direction of the motion.**
- (D) the downward force of gravity and an upward force exerted on the puck by the table.
- (E) gravity does not exert a force on the puck, it falls because of the intrinsic tendency of the object to fall to its natural place.

Question 22: A golf ball driven down a fairway is observed to travel through the air with a trajectory (flight path) similar to that in the depiction below. (Illustration is in original question and omitted here. See Appendix x for the entire inventory.)

Which following force(s) is (are) acting on the golf ball during its entire flight? 1. the force of gravity 2. the force of the “hit” 3. the force of air resistance

- (A) 1 only
- (B) 1 and 2
- (C) 1, 2, and 3
- (D) 1 and 3
- (E) 2 and 3

Question 29: If the force being applied to the box in the preceding problem is suddenly discontinued, the box will:

- (A) stop immediately.
 - (B) continue at a constant speed for a very short period of time and then slow to a stop.
 - (C) immediately start slowing to a stop.
 - (D) continue at a constant velocity.
 - (E) increase its speed for a very short period of time, then start slowing to a stop.
-

Note. The above questions were taken from the article, “Force Concept Inventory” (1992). For a complete list of the questions see Appendix F.

Unlike question 9, the action in question 22, the path of a golf ball after it was hit, is clearly illustrated. Students are asked about the force(s) acting on a golf ball after a hit. Sixty-five to 91% of the students thought that the force of the “hit” acted during the entire flight (Table 3). More of the Arizona students, 30% of the regular students and 29% of the honors students, answered this question correctly than did the students in the study, 5% of the regular and 22% of the GT. This question may have been missed due to the misconception of “impetus supplied by the hit”.

A second example of inconsistent selection of responses corresponding to the same misconception was found also in the “impetus dissipation” questions—5,8,16,23,27, and 29. The percentage of students who missed these question varied greatly, from 0 to 78%. Almost no one selected 29E that said, “... a box moving across the floor with a constant speed would increase its speed for a very short period of time, then start slowing to a stop ... if the force being applied to the box suddenly discontinued.” However, 64% to 81% of the students thought forces other than gravity acted on a steel ball that was thrown straight up (without air resistance) and fell to the ground. Due to the great disparity in correct responses to questions designed to examine the “impetus dissipation” concept, the researcher concluded that the students did not see a correlation between these questions.

In conclusion, after careful examination of the results of the *Force Concept Inventory*, it was found that students could improve on their concepts of kinematics, particularly vector addition of velocities, Newton’s first law with canceling forces, Newton’s second law—path of object after force, and forces on objects after a hit such as

the golf ball in flight. With knowledge of the FCI results and after discussion with the researcher, the teacher altered his syllabus during the next school year and included several simulations and laboratory activities that addressed these misconceptions.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The importance of computer-related instructional technology has been illustrated in this research study. Instructional technology is, however, very expensive for schools and school systems to purchase and to maintain, and technology is time consuming for teachers to learn to use effectively.

In order for more students to have the opportunity to learn physics with these interactive learning tools, many changes have to be made by teachers, school administrators, and school system administrators. Teachers must examine their pedagogy and make appropriate changes to their physics programs when they incorporate technology. School administrators must change the teacher evaluation process to include standards for the effective use of instructional technology in the classroom and for leadership exhibited by teachers who teach others how to use computers, graphing calculators, CBLs, probeware, software, and other resources. School system administrators must continue to seek to have the latest learning tools in their schools, but they must alter the allocation of resources to obtain and to maintain computers as well as to appropriate funds for extensive staff development. As I reflect on what I've learned through this study, I will make recommendations for change within schools and I will share some of the changes that have been made within the school system in the study.

Summary

The seven research questions that guided this research will be addressed below. These questions were found to be good initial guides. However, they were somewhat repetitive, and their answers did not wholly represent the findings in this qualitative study. The discussion of the findings and the recommendations based on the findings are discussed at the end of this chapter. The findings went beyond the initial questions and that is as it should be in a qualitative study.

1. What is the daily teaching practice of this experienced computer-using high school physics teacher?

Teachers who incorporate technology--computers, videodics, videotapes, CD-ROMs, probeware, software, and calculators--into their physics classrooms must, first of all, have excellent teaching skills. Teachers plan instructional programs using a variety of resources and they must know when the use of technology is appropriate. They must constantly be critics of their own teaching as they evaluate when alternate methods should be employed to improve student understanding.

Teachers must know how to address students' conceptual frameworks of common-sense perspectives and how to move students toward more scientifically-based perspectives. One way might be to acquire a better understanding of what Gang (1985) said Robert Karplus originally called the "learning cycle" of exploration, concept invention, and expansion of ideas. Gang discussed the learning cycle approach he applied

in teaching students. The use of technology to alter preconceptions should be more fully explored.

Teachers must be innovators, hard workers, and change agents. One thing that is constant in a technology-rich learning environment is change—change for the betterment of students. The teacher in this study accepts this state of continual change and has moved toward creating learning experiences through whole class instruction, group instruction, and individual instruction. The teacher in this study devotes more time to students who need assistance by taking advantage of the changes in his technology-rich classroom.

2. What are this teacher's expectations of students and instructional technology?

The teacher expects all students to learn physics and to use various resources and technology in the process. On many occasions during the observations, the teacher told students, “You have to know how to do this, too ... Show me how you enter those calculations ... Run the program for me ... Enter the data. ... Do that for me on your calculator. I want to watch you do it.” The teacher expects all students to be able to do calculations on graphing calculators, to become proficient in using the physics computer software, and to learn to problem solve using the technology available. In the process of learning physics, the teacher expects students to learn from each other by working collaboratively. Students therefore learn physics from using technology in a collaborative environment established and monitored by the teacher.

The teacher in this study expects that instructional technology is only as good as his instructional program and epistemology. Computers are aides that enable the teacher

to address the various learning styles of his physics students. Visual learners use the multi-faceted computer screens and the visual in-put that the technology and hands-on experimentation provide. Auditory learners learn from the ample dialogs with the teacher and fellow students. Kinesthetic learners learn from doing the computer-based experiments and projects. The teacher commented on several occasions, “This technology helps me to meet the learning styles of students in ways I was never able to do before.”

The teacher expects that this technology will not be functional all of the time. He has learned to accept the occasional barriers to instruction and he quickly learned to problem solve. For example, when cables from the photogate to the ULI began to malfunction, he and his students spent a frustrating day isolating the problem. Once the problem was identified, he arranged with David Vernier, the developer of the probeware, to have replacement cables shipped by Federal Express. The class was operational again in a short time.

3. What are the physics classroom processes and interactions when computers are used to teach high school students?

The teacher allows students to work in groups on the computers. Students help each other, and the conversations are about the learning task. The classroom is a pleasant place where students enjoyed learning and take pride in the products they produce.

The teacher facilitates learning and creates a meaningful learning environment. The art of questioning and determining when to intervene in the learning experience is one that takes practice and time to develop. This teacher continues to develop his teaching

strategies, even after years of experience. He is learning how to draw students into thinking about what they are learning by asking leading questions. He realizes that he must give enough information to keep students working but not so much that students are prohibited from thinking and problem solving for themselves. The art of questioning has never been easy. Computer-related technology offers students ample opportunity to actively participate in the learning process and challenges teachers to refine their questioning skills. After five years of using the technology, this teacher has not arrived at perfection. The teacher continues to cultivate his teaching strategies and questioning skills as he strives to keep students open and thinking.

The teacher's planning of meaningful technology-related experiments and activities is also a process. Each year the teacher refines his program and lesson plans to reflect what he feels the students should know and be able to do. He keeps abreast of national, state, and local curriculum changes; current physics instructional software and hardware; and learning theories. When he became aware of the research on physics students' common misconceptions, he searched for software and technology-based laboratory experiments that address these misconceptions. In reflecting on the previous' years program and student response to the planned activities, he added more open-ended, experimental-designed laboratories. He is committed to greater student involvement in learning process and to the use technology to assist in that learning process.

4. What barriers and support mechanisms affect the use of technology in this physics classroom?

Most of the original barriers--lack of electrical wiring, lack of teacher training and experience, lack of school system hardware and software contracts--have been worked out over the five years of teacher computer use. Barriers that remain, as observed by the researcher and voiced by the teacher in interviews, are the frequent need for hardware and software upgrades, the lack of reliable and timely maintenance of equipment (technical support), the lack of wiring for student computer access to the Internet, insufficient time for the teacher to learn how to use new software and probeware, and insufficient teacher planning time to implement the computer-based physics program. The main problems were the need for continual upgrades of hardware and software and mismatches of new software with computer memory and/or computer operating systems. As new improved software packages are released, computers have to be upgraded with additional RAM (memory), hard drives, and CD-ROM drives.

There is a constant state of change with instructional technology. Educational software has continued to improve in the 1990s and many of the old machines in the schools simply cannot run the new software. These findings were supported by recent federal documents about technology and teachers (U.S. Department of Education, 1996; U.S. Congress's Office of Technology Assessment, 1995). Teachers, school administrators, and school system administrators must continue to evaluate new software and hardware and to appropriately decide when upgrades are needed to improve the program.

School district administrators, including a coordinator or director of instructional technology and a curriculum specialist, play key roles in assisting teachers and local school administrators in the removal of barriers—facility renovation, staff development, maintenance of equipment, and technical support. The importance of key central personnel is supported by Becker’s findings (1992).

In the school studied, district infrastructure networking and hardware maintenance continue to be barriers, even after five years of implementation. This is due in part to the lack of funding in the area of facility renovation and maintenance. It is costly to shift maintenance operations from repair of relatively low-end technology such as typewriters, record players, and 16 mm projectors to the high-end technology of computers, printers, videodisc players, CD-ROMs, and monitors. Not only must the shops re-tool, personnel must be re-trained or replaced. In order for teachers to use this technology without the barriers of breakdown and lack of network connectivity, adequate provision must be made to provide central technical support either through in-house operations or through outside contractors.

5. How do the students, the teacher, and the technology interact in the learning environment?

With the teacher acting as a planner, facilitator, and evaluator, the students are fairly independent learners in a technology-rich environment. They work collaboratively with each other to solve problems and to learn. Conversations among and between groups of students show that they learn from each other as they interact with the technology.

Students interact with the computer through input from the keyboard and probeware. Prior to any information input, students must actively think about the information that the computer will process. They must think about the required input parameters necessary to make the software and probeware work properly. Examples of such parameter settings are distance, mass, and directions for blocking and unblocking photogates. The computer does the operation that it is told to do by the students. The teacher monitors what students have done. Frequently the teacher asks, “Show me your Set-up . . . Show me your data table . . . Show me your graph.” Students understood that they had to input independent and control variables in many programs, and they were quickly able to illustrate to the teacher their understanding using information on the computer screen.

The teacher and the students interpret the output on the computer screen or printer printout. One of the most valuable ways that the computer can display output is in the form of real-time graphs. Students immediately associate what is happening in the physical or simulated environment with the graphical and numerical representation of the action.

They quickly learn to evaluate the data they collect as valid or invalid and to re-graph data without the data points they mark invalid. Consistent with good scientific practice, they do not erase the data, they mark a line through it and leave it in the data table. They know immediately if they need to collect more data sets. As a result of the technology, students collect many more data sets than they did by conventional means.

The students therefore spend more time in data analysis, and they do so in a time frame closer to the point of collection than they were ever able to do before.

Abstract concepts such as momentum and electrical fields can now be visualized through the use of software and videodisc technology. Computer simulations, with the multi-faceted computer screen output, allow students to associate variable input with the change in action and the graph that represents that action. In the momentum labs the students knew immediately that there were changes in the velocity and momentum during a collision. As they worked through the simulations and corresponding calculations, they understood that momentum is conserved. Students are able to visualize physics concepts and to see results of changes in variables with the use of computer and video technology.

6. What is the unique contribution of computer-related technology to student-teacher and student-student interactions? Are there cognitive representations of computer output that make interaction different from traditional lecture and laboratory methods?

The tasks that students do in a technology-rich classroom are very different from those in a traditional classroom. While the students continue to do hands-on laboratory science, they are able to collect multiple sets of data in a class period, to evaluate the quality of that data and to redo experiments in a short amount of time. The data tables and graphs generated by the computer provide students with quality products from their data collection efforts. Students are able to spend more time in evaluating and analyzing their data. The computer takes much of the drudgery out of performing multiple experiments and allows the students to collect more data than they they could have without the

computer-related technology. The word processed lab reports with embedded graphs and data tables are sources of pride for the students.

The large screen monitor with large letter output, allowed a sight impaired student to take physics and to actively participate in ways that were not possible before. She was able to see the graphs and simulations and she actively talked with her lab partners about the meaning of the graphs such as slope on the velocity-time graphs in Smart Pulley lab or the r/R Vs t graphs in the orbital motion study. The technology uniquely enabled the visually impaired student to not only participate but to become a group leader.

The technology facilitates cooperative learning. The students worked together in groups of 2 to 4 to discuss the concepts in the *Mechanical Universe High School Adaptation* (MUHSA) videotapes. Because they received a group grade for MUHSA quizzes and any student had to be able to defend the group answers, they made sure that all students understood the concepts. During computer simulations and experiments, students worked collaboratively in groups of 2 to 3. They actively talked and discussed among the group members and when problems arose, they asked fellow students for help. If they could not proceed with the activity after these discussions, they asked the teacher for help. This technology changed the interactions and collaboration within this classroom.

7. How do the interactions between the teacher, students, and technology affect student conceptual understanding?

Students' conceptual understandings of physics were evidenced by their dialogs. The interactions with the computers provided visual images of abstract physics concepts.

The simulations such as *Interactive Physics™* allowed students to create experiments in gravity-free environments. The students were able to design experiments in which objects collided or moved and their action was monitored by meters and graphs. Independent variables were changed and students were able to monitor parameters such as velocity, acceleration, momentum, and energy. They were able to add vectors to diagrams and were, therefore, better able to understand scalar and vector quantities in physics. The interaction of the teacher with the technology and with the students was key to student understanding. The teacher played a vital role in planning for and in facilitating the learning process with computers.

Conclusion

Technology such as computers, probeware, software, videodiscs, and videotapes empower teachers and enable most high school students to actively engage in the learning process and to be successful in learning physics concepts. The combination of technology and collaborative learning makes powerful learning experiences for physics students. Although the computer provides many teachable moments, teachers must learn to use and to manage these new instructional technologies. They must plan effective programs by choosing from a plethora of technology resources and applying the new learning tools in creative, meaningful, inquiry-based learning opportunities for students. Learning how to effectively use these instructional technologies is a process, not an event. Teachers who have been using this technology for years still have room for growth and improvement. The teacher in this study is an exemplary mentor teacher and even he needs professional

development opportunities to learn more about student learning with instructional technology.

School systems must be proactive in their support of the technology-using teachers and students. They must renovate facilities, plan and implement technology in areas of greatest instructional need and where students clearly benefit. They must plan and implement a continuous long-term staff development program for teachers and administrators. School systems must provide technical support for teachers and devise a maintenance and technology replacement plan. School systems must be committed to equipping schools with technology in appropriate student-to-computer ratios. In this study of physics instruction, a ratio of 2 to 3 students per computer was shown to be effective.

School administrators must revamp the way they evaluate technology-using teachers. They must become skilled observers as they record evidences of exemplary uses of instructional technology and as they learn to interpret student conversations and actions in the technology-rich classroom.

Discussion and Recommendations

The significance of the findings in this study will be explored from the perspective of five different groups--students, teachers, school administrators, school system administrators, publishers and producers of instructional technology.

Significance for Students

Most high school students can successfully learn physics concepts and should enroll in physics. Many of the students in this study would not have taken physics in other schools in this country, where approximately twenty percent of students take high school physics. The students in this study were primarily bound for colleges, the military services, or technical careers. In the year prior to the introduction of computer-related technology only 30-32% of students in the school in this study took physics. Currently almost 60% of the students in the study school elect physics; clearly the technology has enabled more students to study physics. All students should have the opportunity to enjoy learning and it should not be for only a select few.

The process of learning physics should be fun. Students in the classroom in this study were happy and enjoyed the process of learning. The technology took away much of the drudgery of experimenting in physics. Graphs were made automatically by the computers. Students focused on analysis and evaluation of data.

There are many abstract concepts in physics that can and should be clearly demonstrated in concrete ways. The technology such as probeware and simulations make these abstract concepts more concrete and therefore within the grasp of most students' abilities to understand.

With the probeware and simulations making it easier for students to learn physics, a qualitative introductory course may be developed to include even more students in the study of physical science concepts. *Active Physics* is a new physics course sponsored by

the American Association of Physics Teachers, the American Physical Society, and the American Institute of Physics, and is partially funded by the National Science Foundation. It has potential as a laboratory, computer- and video camera-based course for students who have not traditionally taken physics. Schools should consider options such as this for making computer-based physics courses available to all students.

Classroom learning in this study was inviting and it can be for other students. Students learned that it is okay to ask fellow students for help or to help someone else in the process of learning. The student-centered classroom has multiple resources to engage students in learning. Students have a responsibility for their own learning that is reflected in the conversations and activities that students engage in. Students should be actively “doing” physics and dialoging about physics, not being “talked to” about physics. This classroom climate of collaborative learning and personal responsibility can be established for other students.

Another change for students is the tools they bring to class. Student supplies in technology-rich schools include computer disks and graphing calculators along with pencils and paper. Students learn to use graphing calculators in science and math classes and to apply these skills in other subjects or in solving real-world problems. Schools should allocate resources to purchase graphing calculators in class sets (1 per 2 students). This will ensure that students who cannot afford these tools will also learn to use them.

Significance for Teachers

Technology is only a tool for effective teachers. However, even exemplary teachers do not exit college knowing how to use all of the instructional technology discussed in this study. Pre-service teacher programs will eventually change to better prepare teachers to use instructional technology. However, with the intensive use of multiple probeware and simulation activities, there must be continuous local staff development opportunities for new teachers. Staff development at the local level must be through a variety of delivery modes--college-credit and academic-credit classes, institutes, mentor-teacher programs, and one- and two-day inservices.

This need for extensive staff development presents a problem to teachers in small school systems. They may have to seek regional summer institutes or seminars. Several small school systems in a region might pool resources to obtain training for all of their teachers. Teachers of large school systems and curriculum directors should collaboratively develop a comprehensive long-range and short-range staff development plan. Suggestions for specific courses are discussed in the Significance for School Systems section below.

Student Misconceptions in Physics and Instructional Technology

The research on physics misconceptions of students and use of the learning cycle in instruction should be explored by teachers as they plan units of study. Simulations and key probeware experiments can be planned to help students develop alternate conceptions.

Teachers should consider using the *Force Concept Inventory* as one means of assessing students' common sense beliefs about force. The teacher in the study adjusted

his lesson plans to include simulations and experiments that addressed the kinematics and force “misconceptions” identified in the study. The year after the study the teacher added three *Interactive Physics II™ Simulations* activities to address Newton’s first and second laws—*Grape Drop, g Force, and Parachutist*.

Teachers might consider altering the FCI slightly to compensate for the questions of validity mentioned in this paper and in other publications (Hestenes and Halloun, 1995, Huffman and Heller, 1995a, 1995b). Teachers may wish to investigate the “improved” version of FCI by Hake, Halloun, and Mosca. Hestenes (1995) said that it “does not significantly affect numerical results” (p. 506). The newer version was published after the data were collected for this study and has not been explored by the researcher.

When teachers use the FCI, they should consider analyzing, in detail, the non-Newtonian responses of the students, and students should be interviewed for a clearer understanding of student beliefs. In this study, students could not be interviewed after the inventory was administered to determine if they had questions about the inventory. Teachers should take advantage of the opportunity they have to explore student thinking.

This knowledge of students’ preconceptions can then be applied, as Gang (1995) described, using Robert Karplus’ learning cycle of exploration, concept invention, and expansion of ideas. The use of inquiry-based probeware experiments and simulations using computers should be based on teachers’ knowledge of students and learning.

Willingness to Change and Time for Change

The change in instruction at the classroom level will take time. The teacher under observation in this study has been using computer-related technology for five years and is still making changes in instruction as he learns more about how students learn and about new software programs. A teacher must simply start somewhere and be willing to spend the time and effort it takes to learn to use technology that enables students to learn physics.

Assessment of Students

Assessment of student work will change in accordance with the tools they use and the objectives teachers develop. Student grades should not be determined merely by paper and pencil quizzes and tests, especially as instructional technology is incorporated into the physics program. Student products such as HyperCard stacks, word processed lab reports, and computer-generated graphs with statistical analysis should be considered as major components of a student's grade. In addition, there are issues that must be resolved concerning grading policies for group and individual work.

Learning to assess students is not an easy task and assessment strategies should be shared with fellow teachers as computer-using teachers develop them. Performance assessments such as the ones used by the teacher in this study should be a part of computer-using teachers' repertoire. The teacher asked students to illustrate that they knew how to perform certain computer operations such as setting the parameters for a

probeware experiment. This process of learning to use software and hardware should also be a part of assessment.

As formal assessment of student learning changes with technology use, the informal assessment that comes through observing and asking questions also changes. The teacher's technique of asking individual and group questions has to be refined. The teacher's skill at guiding instruction through questioning is critical as students take more control of their own learning. The teacher in this study continues to alter his teaching strategies as he learns more about teaching with computers. Sometimes he gave too much information instead of allowing students to determine for themselves how to solve a problem. As the technology allows teachers more teachable moments, teachers need to be aware of questioning techniques and how to improve their techniques. Students want to think more for themselves. Judith said many times during the period of observation, "Don't tell me the answer, tell me how to do it." Teachers need to learn the art of questioning and guiding instruction so that students know "how to do it" for themselves.

Teacher Directions to Students and Handouts

Not only will student assessment change, the handouts and other work products that teachers produce for students will also change with the use of instructional technology. Many questions occurred over and over again in this classroom as students used computers and software. Some of these questions might have been answered if the teacher had prepared a handout or instructional booklet with hints such as how to save files, how to print documents, how to input formulas into spreadsheet cells, and how to

create graphs for each of the programs that the students worked with. These handy reference notes could be laminated or bound in a notebook and left by each computer.

Organization and Classroom Management

Teachers who use or who are learning to use computers should establish a method of organizing handouts in files easily accessed by students. The teacher's method described in this paper was efficient and the practice of providing class sets of papers instead of individual copies worked well and saved money and time. These materials were kept from year to year. For those documents that required alteration, the teacher organized his files on the computer so that they could be accessed, altered, reprinted, and duplicated.

The teacher created many curriculum materials that were not only kept in paper files, they were also kept on computer files. Organizing the computer files for ease of student access is a learned process. As more and more programs become available, the teacher has to think about how these will be loaded onto the machines for student use. The teacher in the study came to appreciate the advantages of a commercial "lock-out" program, *At Ease*, to keep the hard drives of the student computers organized. He found that students were better able to find the software programs they needed since each program had a unique icon. In addition to accessing programs, students saved work to an electronic folder that the teacher established on the hard drive of his computer. The teacher was better able to view and assess student work products with this improved method of organizing computer files.

Planning a Technology-Rich Physics Program

With multiple resources for teaching students physics, teachers must look holistically at the school year and determine the sequence of activities and experiments they will incorporate into the introductory physics course. Not only must teachers spend time to learn what resources are available, they must plan how to use these resources effectively. Planning is one of the most important activities of the computer-using teacher. Teachers must not get caught up in using the technology for technology's sake, but they must look at the pedagogical value in the use of the technology.

Videotapes and videodiscs play import roles in presenting ideas and concepts to students. Teachers are more actively involved in creating a learning environment than ever before. Videotapes with appropriate strategies and instructional handouts are very valuable learning tools. The teacher in this study used *the Mechanical Universe High School Adaptation* (MUHSA) videotapes and resource handbook (1987) for teachers. These excellent materials contain many strategies for teaching physics. MUHSA was co-produced by the California Institute of Technology, the University of Dallas, and the Southern California Consortium.

Teachers who use technology will be in a constant state of change. Hardware and software must be upgraded in a reasonable time frame. Not every new change in software need be adopted, but the teacher must evaluate new products and determine when change to the current program is needed. In a never-ending quest to provide new learning opportunities for students, the teacher in this study expressed the desire to make greater

use of the Internet in his physics classes. How the Internet can be used by students to research current topics in physics and to share data among groups of students locally, nationally, and globally remains to be explored by the teacher in this study and is an area for further research.

Significance for School Administrators

Administrators are evaluators of teachers in most school systems and they are charged with leading the instructional program. Most of them have never taught with computer-related technology and do not know first-hand the time, energy, and effort that is necessary to provide a technology-rich learning environment for students. School administrators must spend time talking with teachers and students and observing classes in which these technology are used. They should be invited to participate in the staff development of teachers, perhaps on a day when teachers present lessons they have created that incorporate technology.

Evidence of Computer Use

Administrators should learn to look for evidences of frequent student use and long-range planning by teachers. They will find teachers spending less time in front of the classroom and more time assisting individuals or groups in learning. They will find rooms re-arranged. Desks or lab tables will not longer be facing the board during the entire lab period but will be arranged for cooperative learning and computer use.

Teacher planning and personal use of the computer will be evident in word processed documents and spreadsheets of student grades or grade reports from

commercial gradebook programs that store and calculate student grades. Students should know their grades on a more frequent basis as well as what work needs to be made up. Teachers who use gradebook programs are able to print out individual reports for students, counselors, and parents.

During classroom observations, administrators should find students in a variety of activities: viewing videotapes, discussing concepts with the teacher or in small groups, completing interactive simulations, conducting laboratory experiments with probes and being assessed in multiple ways. These computer-based physics classrooms will not be quiet places but will be filled with conversations of students actively engaged in learning.

Administrative Support for Technology-Using Teachers

Administrators can help teachers by providing time during the school day for teachers to learn new software programs, by arranging for broken equipment to be repaired in a timely manner, by creating a school-wide technology committee which will assist in making technology policies for the school, by reallocating staffing to create a technology resource teacher or assistant position, by funding upgrades of software and hardware when appropriate, and by helping parents and the community to understand the change in the classroom environment.

Sometimes school administrators can provide substitute teachers to allow a classroom teacher to have the time to learn new programs. At times administrators can even offer to teach a class to allow teachers time to learn the new technology.

As more and more computers become a part of the school, administrators should consider forming a technology committee which will make recommendations for school-wide network software and hardware. This committee could identify software that should be purchased on a schoolwide basis and help in planning for full utilization of computers in the school. They could also plan school-based staff development courses or inservices.

In addition to the technology committee, a technology resource teacher or teaching assistant should be identified and given special training to assist teachers as they become more adept at using technology with students. This teacher or teaching assistant might be released from all or part of his/her duties to become a technology specialist for the entire school. This person should be given opportunities to provide special "in-house" staff development for all teachers. Teachers are better able to help other teachers because they have the experience of the classroom and know best how technology can be used as instructional tools.

Administrators are usually in charge of allocating funds for instructional materials and should consider how these scarce funds can best be used to provide a variety of resource materials for students. The days of each student having an individual textbook may be coming to an end. As teachers and students are able to access current reading materials from the Internet and CD-ROMs, whole textbooks may become a relic of the past. CD-ROMs, software, videodiscs, videotapes, and print materials may now be considered basal. Perhaps the replacement of textbooks can be delayed as new non-textbook curriculum materials are purchased. Local school administrators, teachers, a

technology committee, parents, and students should identify resources that best meet the needs of students in a technology-rich environment.

Significance for School System Administrators

The decisions of what to use instructional technology for and how to fund and maintain technology should be a joint decision of teachers, school administrators, parents, students, and central administrative personnel. Central school system administrators should play an important role in planning for and in implementing plans to use instructional technology. Becker found in his 1992 survey that top-down (central technology coordinator) decision making can produce better results in instructional computer use than school-based decisions (Becker, 1992). With either a committee or central decision making process, school systems must spend funds on technology. Adequate funds must be provided for hardware, software, maintenance, technology support, and staff development.

Hardware

Not all technology funds should be used for hardware; however, there is a critical mass of computers needed in a classroom for students to have adequate learning experiences. The ten computers, or 2:1 to 3:1 ratio of students to computers in the classroom in this study, provided adequate opportunities for students to learn physics. The critical mass of computers in the physics classroom is more than the five computers per general classroom recommended in the U.S. Department of Education's report, *Getting America's Students Ready for the 21st Century* (1996).

Physics is a hands-on science that is laboratory-based and a ratio of more than 3 students per computer, the researcher believes, would not be as effective. Most physics teachers in the school system where the study took place work with group sizes of two to three. The effectiveness of larger groups in terms of student achievement might be explored in future studies.

In this research study, when two or three students shared a computer, every student had a task and they worked collaboratively to complete the laboratory experiments or simulations. If more students share a computer, students will have less opportunity for direct learning with the technology.

High school physics teachers now have ample resources in video materials, probeware, and software to use during the entire school year. Students in this study demonstrated in their dialogs that they were actively engaged in learning physics and the computers were integral components in that learning process. For school systems who plan to place computers in high schools, physics classrooms would be a good place to begin and the ratio of students to computers should not exceed 3 to 1.

Software

As important as hardware is, it is nothing without good instructional software. The software in this study greatly contributed to students learning physics. School systems need to negotiate for system software contracts and should work with teachers to upgrade software as major improvements to software programs become available. System or school network license agreements should allow for increases in the number of machines

at a school as computers are phased in over a period of years. Teachers interviewed in this study said that they spent many hours outside of school learning to use the programs. All of them use weekends and summers to learn new programs. Software contracts should allow teachers to use software programs at home.

Maintenance and Replacement

Concurrent with placing computers in schools, funds should be available for maintenance and replacement of hardware and software. During the research study, several computers in the classroom had to be restarted because the software “bombed” due to lack of memory. Students quickly learned to compensate, to some extent, by closing active windows and thus, limiting what was “open” at any one time. By the end of the study, it was evident that the computers had to be upgraded to run the more memory-demanding simulations. After the school year, the school district upgraded these computers to machines with more memory. Maintenance and replacement due to obsolescence is necessary and school systems should include maintenance funds in any long-range technology plans.

Smaller school systems might need to contract-out repair and maintenance services. However these services are provided, teachers and administrators must work together to ensure that the computers are kept operational. The teacher cannot be expected to be totally responsible for following up on computer repair. One of the barriers to computer use identified in this study was lack of adequate technology support in the first few years that computers were in the school.

Technology support continues to be a barrier but to a lesser extent now as the system has worked to improve support facilities and increase support personnel. When major changes have been made in the use of technology, the school system must contract for commercial repair and maintenance or provide a mechanism for “in-house” repair. The classroom teacher has to focus on instruction and the burden of keeping the computers operational should be removed from the teacher’s shoulders.

Staff Development

School systems should continually provide staff development opportunities for teachers. There is no ideal time for staff development. One-day inservices can, at best, be information sharing sessions, but real learning and change in instruction must occur over longer periods of time. The school system in this study planned several 15 to 40 hour courses or institutes for teachers after school and in the summers. The opportunities began in 1986 and continue to evolve as the instructional technology and teacher needs evolve. Other school systems have scheduled staff development time during the school day. No matter what the schedule, teachers are professionals who must continue to develop their skills. Knowledgeable school boards allocate adequate funds for staff development on a continuing basis. Every physics teacher will need approximately 20 to 80 hours per year of staff development to become and remain proficient in the use of instructional technology.

Physics teachers need a variety of staff development courses to support instruction. Courses are needed in word processing, databases, spreadsheets, individual instructional software programs, student learning styles, student misconceptions in

physics, constructivism and other learning theories, assessment, and cooperative learning. The misconceptions that students have about physical phenomena discussed in the study should be a part of any technology course for teachers since instructional technology can be used to help students have a clearer understanding of abstract concepts. As teachers learn to use the probes and simulations, they need to develop a plan to use this technology with students. Matching arrival of equipment, staff development, and application in the classroom is no easy feat. Immediate application of ideas and learned skills is important. Staff development is “time-sensitive” and should match availability of technology. Teachers must have the technology resources and have time to learn the mechanics of hardware and software before they are expected to implement these resources in the classroom. As was stated before, learning to use and using instructional technology is a process, not an event.

Table 8 reflects the staff development courses that have evolved in the school system in the study. Yearly or twice-yearly full-day inservices should be planned for teachers to share successful laboratory experiments or simulations and teaching strategies. School systems that embark on the use of technology in instruction must realize that this is an on-going process. The time for teachers to learn to use the technology in the classroom differs, but it is usually three to seven years before they are truly comfortable. The teacher in this study has now been using the technology for five years and he continues to change every year as he learns more about how students learn and as he explores the new resources available.

Table 8.

Technology-Related Staff Development Courses for Physics Teachers

TITLE	HOURS	DESCRIPTION
Introduction to the Macintosh (or PC)	5	Participants learn about the operating system, save, print, and network features.
Word Processor Techniques	15	Participants learn features of the word processor.
Spreadsheet and Graphing Techniques	15	Participants learn features of spreadsheets and graphing programs.
CBL and Graphing Calculator	40	Participants learn features of the graphing calculator including beginning statistics, graphing, data transfer to computer, CBL, and probeware.
Interactive Physics	15	Participants learn features of the IP program and create several simulations.
Logal Physics Explorer	30	Participants learn basic features of all programs, create handouts, and learn advanced features of Physics Explorer software.
Introductory Probeware	15	Participants learn to use motion detector and force probe and perform mechanics lab experiments using Pasco Dynamics Carts.
Advanced Probeware	15	Participants learn to use microphone, electrical probe, magnetic field sensor, and light sensor.
Internet Resources	15	Participants explore physics web sites and download files.
Strategies for Teaching and Assessing Students in Physics	15	Lead by a mentor teacher, participants share computer and traditional strategies that work to alter student misconceptions and assess student progress. They learn to use grading programs, assessment rubrics, and videodiscs and associated software.
MUSHA Workshop	30	Participants learn to use MUSHA videotapes and teacher materials

Note: MUHSA = Mechanical Universe High School Adaptation. CBL = Calculator-Based Laboratory . The Logal Physics Explorer course is based on 5 hours per package on the 6 packages initially adopted. All hours are recommended hours of instruction and should be augmented by an equal number of hours outside of class. The courses listed should be done over a period of time. Approximately 3 years is a recommended time frame for completion of training listed above.

The courses recommended in Table 8 may be provided by selected teachers within the district who have become “experts” or may be presented by consultants. Vernier Software, Pasco Scientific, and Logal Educational Software are just a few of the companies who have educational consultants available to assist school systems in science teacher professional development.

Block Scheduling and the Use of Instructional Technology

The traditional 45 to 50 minute period for high school classes has never been conducive to learning hands-on science and now, with the use of computer-related technology, students need even longer periods of time to engage effectively in the learning process. Fairly common laboratory experiments and simulations can easily take 90 to 180 minutes to complete. The school in the study has changed to a semester-semester block schedule. The teacher, at the time of the study, was in his first year of block-scheduling and he has since improved his physics program to use even more computer activities and long-term student projects. As school systems plan for increased use of instructional technology, they should consider the various models of block scheduling to allow students longer periods of time to engage in using these new learning tools.

Facility Renovations

The electrical and network wiring of the physics classroom in this study had to be improved to accommodate 10 student computers, 1 teacher computer, and other technology. With the experience of the study, the researcher made the following recommendations for construction of new physics classrooms or renovations of old rooms.

- Increase classroom size to 1400 sq. ft. (1 teacher multimedia station, 10 student lab stations, 28 students).
- Increase electrical outlets to a minimum of 5 per wall with sufficient current to accommodate computers and other physics electrical lab equipment. Put a quadjack drop on all four walls in logical places for computer, scanner, and printer use. Investigate other connectivity options.
- Lower lab benches on three sides of the room to table height with adequate width to accommodate computers and with adequate length to accommodate 2.2 m Pasco Dynamics Tracks. Make lab benches in physics without sinks, except for the wall at the rear of the class; place one deep sink at the back of the room.
- Furnish the room with 14 six foot tables, a movable 10 foot teacher demonstration table, bookcases, teacher wardrobe, and storage cabinets. The tables should not be fixed in place but should be movable for collaborative groupings.
- Change the traditional black board to either a white board or a board that uses both dustless chalk and water-soluble markers.
- Allow adequate room at the front of the room for a teacher computer, desk, and multimedia cart.
- Allow adequate storage for traditional physics equipment in a back storage room. Make shelves movable and of differing widths. Some shelves should be as wide as 2.5 feet (.75 m) and others as narrow as 1 foot (.3m) Allow room for movable carts with equipment such as vacuum pumps and multimedia equipment.

- In the classroom, under the lab benches, provide a set of drawers for every computer to store probeware and other computer-related materials.
- Provide for storage of computer software, CD-ROMs, videodiscs, and teacher reference materials near the teacher's desk. Provide bookshelves for multiple sets of reference books and disk box storage in the back of the room for student use.

Significance for Publishers and Producers of Instructional Technology

Publishers of high school text books and software and producers of instructional technology could benefit from this study. The teacher had to create many of the lab experiments that he used in the classroom. Current laboratory manuals that accompany student texts do not utilize instructional technology, nor are they based on overcoming students common sense beliefs about the physical world. Few are inquiry based. The teacher resources that are available have to be individualized and copied such as *Real Time Physics* (Sokolof et. al., 1995) or *Tools for Scientific Thinking Motion and Force Laboratory Curriculum and Teachers' Guide* (Sokoloff & Thornton (1990-92). Textbook publishers should consider working with teachers and technology producers such as Vernier Software to incorporate computer probeware and graphing calculators into their texts and laboratory manuals.

Student conversations reveal problems with directions in procedures of commercially produced materials that accompany software. High quality ancillary materials should be available. Some of the commercially produced materials need to be changed for clarification. I would recommend that software publishers hire experienced

exemplary technology-using teachers to edit materials once they have been in use for a year. Many of points of difficulty for students could be eliminated. These edited versions of the print materials could be advertised and sold to schools at minimum cost.

More of these commercially prepared teacher materials should be on disks to allow local teachers more flexibility in producing instructional handouts for their students. The Vernier Software print materials allow for teacher changes and have been used extensively by physics teachers. More graphics- and memory-intensive curriculum materials might be put onto CD-ROMs.

Commercial companies need to offer more staff development opportunities for teachers at reasonable costs. Texas Instruments has recently developed a staff development grant program in which they collaborate with the school district to provide quality staff development programs for math and science teachers who use TI graphing calculators and CBLs. Other producers of textbooks, technology hardware, and software should emulate the Texas Instrument staff development program.

Staff development opportunities should be based on the experience of teachers and students who use their products. It is not enough for teachers to merely learn the technical nuts and bolts of using a piece of software or hardware. They also need to understand better how these materials can be used to help students learn. Teachers need to know more about how students learn, how to assess student work products, and how to determine what misconceptions or pre-conceived ideas students have about the physical

world. Teachers need a clearer vision about how technology can be used in instruction to alter misconceptions and support valid ideas.

Ideas for Further Study

Further investigation is needed to determine effective intervention techniques and appropriate timing as teachers facilitate student learning in the technology-rich classroom. The teacher needs to understand how to function in the computer classroom in order to help students to develop critical thinking skills. He also needs to know when to intervene in conversations, how long to intervene in order to direct the learning, and how to ask critical questions that keep students open and thinking.

The teacher in this study sometimes gave too much information and at other times did not give enough to student groups as they problem solved. At times the right degree of guidance enables students to successfully conduct scientific inquiries to solve problems as they develop higher-level problem solving skills. There seem to be techniques of questioning and teacher intervention in student learning with computers that need to be further refined. Determining the optimal intervention would be very useful to teachers and students. It would be interesting to design a study around teachers who are given special instruction in constructivist theory, the learning cycle, and assessment strategies and are asked to apply this knowledge using computer and video resources available to them.

A second area of further research complementary to the first, is to investigate further how computer technology can be used to alter students misconceptions about the physical world. There is a body of recent research about what students believe about the

natural world and the factors that influence conceptual change (Brown, 1992; Clement, 1993; Dykstra, Boyle, & Monarch, 1992; Fetherstonehaugh & Treagust, 1992; Fisher & Aufschnaiter, 1993; Galili, 1993; Gang, 1993; Roth, 1993a, 1993b; Sandanand & Kess, 1990; Vicentini, 1993). These student ideas have been labeled many things--preconceptions, non-Newtonian ideas, pre-instruction knowledge, non-scientific, misconceptions, alternative conceptions, or alternative frameworks. No study has looked holistically at using a combination of simulations, MBLs, CBLs, videodisc, and videotape technology as well as hands-on laboratories to influence conceptual change. While there are many interesting studies that can be done to determine how educators might improve their epistemologies, no one is advocating the abandonment of computer-technology.

In conclusion, I would like to end with a quote from the classroom. Suzi said, "I can't image learning physics without these computers." Her teacher, building administrators, and the school system have made this experience possible for her. She doesn't know what students did in physics before computers, nor does she want to know. School system leaders must provide teachers and students with the technology and support that are necessary for effective instruction.

LITERATURE CITED

- Anderson, R. E. (1993, May). The technology infrastructure of U.S. schools. *Communication of the ACM*, 16, 72-73.
- Becker, H. J. (1991). Mathematics and science uses of computers in American schools, 1989. *Journal of Computers in Mathematics and Science Teaching*, 10 (4), 19-25.
- Becker, H. J. (1992). Top-down versus grass roots decision making about computer acquisition and use in American schools. *Proceedings of the Annual Meeting of the American Educational Research Association, San Francisco, CA*. (ERIC Document Reproduction Service No. ED356 769).
- Becker, H. J. (1993a, April). Instructional computer use: Findings from a national survey of school and teacher practices. *The Computing Teacher*, 6-7.
- Becker, H. J. (1993b, May). Teaching with and about computers in secondary schools. *Communication of the ACM*, 16, 69-72.
- Becker, H. J. (1994). How exemplary computer-using teachers differ from other teachers: Implications for realizing the potential of computers in schools. *Journal of Research on Computing in Education*, 20, 291-321.
- Bly, C. S. (1993). Technology-related staff development: Teacher concerns and perceptions (Doctoral dissertation, University of La Verne, 1993). *Dissertation Abstracts International*. (University Microfilms No. 9407207)
- Bradley, M. J. T. (1992). Teacher-student interactions in computer settings: A naturalistic approach (Doctoral dissertation, Memphis State University). *Dissertation Abstracts International*, A 53/12. (University Microfilms No. 9311434)
- Bradley, M. J. & Morrison, G. B. (1991). Student-teacher interactions in computer settings: A naturalistic inquiry. Memphis State University. (ERIC Document Reproduction Service No. ED 343 565)
- Bromley, D. B. (1986). *The case-study method in psychology and related disciplines*. New York: John Wiley & Sons.

- Brown, D. E. (1992). Using examples and analogies to remediate misconceptions in physics: Factors influencing conceptual change. *Journal of Research in Science Teaching*, 29, 17-34.
- California Institute of Technology, University of Dallas, & Southern California Consortium. *The mechanical universe high school adaptation*. In K.A. Martin (Ed.). CA: Author.
- Cline, M. G. (1994a). *Characteristics of inductive designs: Outline*. Unpublished manuscript. Virginia Tech, Blacksburg.
- Cline, M. G. (1994b). *Some notes on properties of research issues which justify inductive approaches*. Unpublished manuscript. Virginia Tech, Blacksburg.
- Collins, Allan (1990). The role of computer technology in restructuring schools. In K. Sheingold & M. Tucker (Eds.), *Restructuring for learning with technology* (pp. 31-48). New York: Center for Technology in Education Bank Street College of Education and the National Center on Education and the Economy. (ERIC Document Reproduction Service No. ED 341 383)
- Conery, L. G. (1993). Teacher beliefs about computers in the classroom: Three case studies (Doctoral dissertation, University of Oregon, 1992). *Dissertation Abstracts International*, A 53/10. (University Microfilms No. 9305186)
- Cuban, L. (1986). *Teachers and machines: The classroom use of technology since 1920*. New York: Teachers College Press.
- Cuban, L. (1989). Neoprogressive visions and organizational realities. *Harvard Educational Review*, 59, 217-222.
- David, J. L. (1990). Restructuring and technology: Partners in change. In K. Sheingold & M. Tucker (Eds.), *Restructuring for learning with technology* (pp. 73-87). New York: Center for Technology in Education Bank Street College of Education and the National Center on Education and the Economy. (ERIC Document Reproduction Service No. ED 341 383)
- Dede, C. (1990). Imaging technology's role in restructuring for learning. In K. Sheingold & M. Tucker (Eds.), *Restructuring for learning with technology* (pp. 49-72). New York: Center for Technology in Education Bank Street College of Education and the National Center on Education and the Economy. (ERIC Document Reproduction Service No. ED 341 383)

- Duesen, J. D. van, & Duesen, R. M. van. (1989, November). Don't buy computers unless *Principal*, 10-12.
- Dwyer, D. (1994, April). Apple classrooms of tomorrow: What we've learned. *Educational Leadership*. 4-10.
- Dwyer, D. C., Ringstaff, C., & Sandholtz, J. H. (1990a). *Teacher beliefs and practices part I: Patterns of change, the evolution of teachers' instructional beliefs and practices in high access-to-technology classrooms, first-fourth year findings*. (ACOT Report # 8). Cupertino, CA: Apple Computer.
- Dwyer, D. C., Ringstaff, C., & Sandholtz, J. H. (1990b). *Teacher beliefs and practices part II: Support for change, the evolution of teachers' instructional beliefs and practices in high access-to-technology classrooms, first-fourth year findings*. (ACOT Report # 9). Cupertino, CA: Apple Computer.
- Dykstra, D. I., Boyle, C. F., & Monarch, I. A. (1992). Studying conceptual change in learning physics. *Science Education*, 76, 615-652.
- Eylon, B., & Linn, M. C. (1991). Models and integration activities in science education. In Bar-on, E., Scherz, A., & Eylon, B. (Eds.). *Designing intelligent learning*. Norwood, NJ: Ablex Publishing.
- Fetherstonehaugh, T., & Treagust, D. F. (1992). Students' understanding of light and its properties: Teaching to engender conceptual change. *Science Education*, 76, 653-672.
- Galili, I. (1993). The effects of prior knowledge and instruction on understanding image formation. *Journal of Research in Science Teaching*, 30, 271-301.
- Gang, B. S. (1993). On students' preconceptions and a special self-regulation. *The Physics Teacher*, 31, 414-418.
- Gang, B. S. (1995). Removing preconceptions with a "learning cycle." *The Physics Teacher*, 33, 346-354.
- Guba, E. G., & Lincoln, Y. S. (1981). *Effective evaluation*. San Francisco: Jossey-Bass Publishers.
- Hakerem, G., Dobrynina, G., Hurwitz, C., Shann, M., & Shore, L. (1993). A case study of the introduction of risc-based computing and a telecommunications link to a suburban high school. Boston, MA: Boston University, Center for Polymer Studies. (ERIC Document Reproduction Service No. ED 361 212)

- Hadley, M., & Sheingold, K. (1993). Commonalties and distinctive patterns in teachers' integration of computers. *American Journal of Education*, 101, 261-315.
- Hasson, B., & Bug, A. R. (1995). Hands-on and computer simulations. *The Physics Teacher*, 33, 230-236.
- Harlen, W. (Ed.). (1985). *Primary science taking the plunge*. London: Heinemann Educational Books.
- Hass, J. M. (1993). Educational computing and the practice of teaching: A case study. (Doctoral dissertation, University of Wisconsin-Madison, 1992). *Dissertation Abstracts International*. A 54/02. (University Microfilms No. 9304157)
- Hestenes, D., & Halloun, I. (1995). Interpreting the force concept inventory; a response to March 1995 critique by Huffman and Heller. *The Physics Teacher*. 33, 502-506.
- Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*. 30, 141-153.
- Hoffer, T., Radke, J., & Lord, R. (1992). Qualitative/quantitative study of the effectiveness of computer-assisted interactive video instruction: The Hyperacid table of elements. *Journal of Computers in Mathematics and Science Teaching*, 11, 3-12.
- Hoffman, B. (1994, September/October). New tools for teaching science: To stimulate, simulate. *The Harvard Education Letter*, 4-5.
- Huffman, D., & Heller, P. (1995a). What does the force concept inventory actually measure? *The Physics Teacher*, 33, 138-144.
- Huffman, D., & Heller, P. (1995b). Interpreting the force concept inventory; a reply to Hestenes and Halloun. *The Physics Teacher*, 33, 503-509.
- Kelly, G. J., & Crawford, W. (1996). Students' interaction with computer representations: Analysis of discourse in laboratory groups. *Journal of Research in Science Teaching*, 33, 693-707.
- Kolderie, T. (1990). How structural change can speed the introduction of technology. In K. Sheingold & M. Tucker (Eds.), *Restructuring for learning*

with technology (pp. 88-100). New York: Center for Technology in Education Bank Street College of Education and the National Center on Education and the Economy. (ERIC Document Reproduction Service No. ED 341 383)

Krajcik, J. S., & Berg, C. (1987, October). Exemplary software for the science classroom. *School Science and Mathematics*, 494-500.

LaFrenz, D., & Friedman, J. E. (1989). Computers don't change education, teachers do! *Harvard Education Review*, 59, 222-224.

Laws, P. W., Boyle, R. J., Luetzelschwab, J., Sokoloff, D., & Thornton, R. (1994). *Workshop Physics II Activity Guide*. Portland, OR: Vernier Software.

Layman, J. W. (1984). Micro-computers as laboratory instruments. In: E. J. Wenham (Ed.) *New trends in physics teaching* (pp. 297-300). UNESCO.

Layman, J. W., and Krajcik, J. S. (1992). The microcomputer and practical work in science laboratories. in: *Innovations in science and technology education, IV*, (pp. 1-9). reprint of UNESCO Teaching of Science Series.

Linn, M. C. (1991). The computer as learning partner: Can computer tools teach science? Manuscript submitted for publication.

Linn, M. C., & Songer, N. B. (in press). Cognitive and conceptual change in adolescence. *American Journal of Education*.

Linn, M. C., & Songer, N. B. (in press). Teaching thermodynamics to middle school students: What are appropriate cognitive demands? *Journal of Research in Science Teaching*

Linn, M. C., Songer, N. B., Lewis, E. L., & Stern, J. (in press). Using technology to teach thermodynamics: Achieving integrated understanding. In Ferguson, D. L.(Ed.). *Advanced technologies in the teaching of mathematics and science*. Berlin: Springer-Verlag.

Maor, D., & Taylor, P. C. (1995). Teacher epistemology and scientific inquiry in computerized classrooms environments. *Journal of Research in Science Teaching*, 32, 839-854.

Marcinkiewicz, H. R. (1993/94). Computers and teachers: Factors influencing computer use in the classroom. *Journal of Research on Computing in Education*, 26, 220-237.

- Mathison, S. (1988). Why triangulate? *Educational Researcher*, 17(2), 13-17.
- Merriam, S. B. (1988). *Case study research in education a qualitative approach*. San Francisco: Jossey-Bass Publishers.
- Miles M. B., & Huberman, A. M. (1994). *An expanded sourcebook qualitative data analysis*. Thousand Oaks, CA: Sage Publications.
- Naimi, L. L. (1990). How elementary teachers use computers. *Dissertation Abstracts International*. (University Microfilms No. 90324)
- National Research Council. (1996). *National science education standards*. National Academy of Sciences. Washington, DC: National Academy Press.
- Olson, J. (1988). *Schoolworlds/microworlds: Computers and the culture of the classroom*. Oxford, UK: Pergamon Press.
- Osborne, R. J., & Freyberg, P. (1985). *Learning in science: The implications of children's science*. London: Heinemann Educational Books.
- Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books.
- Quality Education Data, Inc. (1994-95). *Education mailing lists market guide*. Denver, CO: QED.
- Quality Education Data, Inc. (1992). *Ed. Tech Trends*. Denver, CO: QED.
- Ringstaff, C., Sandholtz, J. H., & Dwyer, D. C. (1990). Trading places: When teachers utilize student expertise in technology-intensive classrooms. (ACOT Report # 15). Cupertino, CA: Apple Computer.
- Roblyer. M. D. (1988, September). The effectiveness of microcomputers in education: A review of the research from 1980-1987. *T. H. E. Journal*, 85-89.
- Ronen, M., Langley, D., & Ganiel, U. (1992). Integrating computer simulations into high school physics teaching. *Journal of Computers in Mathematics and Science Teaching*, 11, 319-329.
- Roth, W.-M. (1993a). Problem-centered learning for the integration of mathematics and science in a constructivist laboratory: A case study. *School Science and Mathematics*, 93(3), 113-122.

- Roth, W.-M. (1993b). The concept map as a tool for the collaborative construction of knowledge: A microanalysis of high school physics students. *Journal of Research in Science Teaching*, 30, 503-534.
- Roth, W. -M. (1995). Affordances of computers in teacher-student interactions: The case of Interactive Physics™. *Journal of Research in Science Teaching*, 32, 329-347
- Ryan, A. W. (1990). Meta-analysis of achievement effects of microcomputer applications in elementary schools. *Dissertation Abstracts International*. 51/12-A. (University Microfilms No. 9113106)
- Sandanand, N., & Kess, J. (1990, November). Concepts in force and motion. *The Physics Teacher*, 28, 530-533.
- Sandholtz, J. H., Ringstaff, C., & Dwyer D. C. (1990a). *Classroom management teaching in high-tech environments: Classroom management revisited first-fourth year findings*. (ACOT Report # 10). Cupertino, CA: Apple Computer.
- Saphier, J., & Gower, R. (1987). *The skillful teacher building your teaching skills*. Carlisle, MA: Research for Better Teaching.
- Schwartz, J. L. (1989). Intellectual Mirrors: A step in the direction of making schools knowledge-making places. In Symposium: Visions for the use of computers in classroom instruction. *Harvard Educational Review*, 59, 51-61.
- Schwarz, C., & Tavel, P. (1993). The use of Interactive Physics in introductory physics laboratories. *AAPT Announcer*, (23), 93.
- Sheingold, K (1990). Restructuring for learning with technology: The potential for synergy. In K. Sheingold & M. Tucker (Eds.), *Restructuring for learning with technology* (pp. 12-30). New York: Center for Technology in Education Bank Street College of Education and the National Center on Education and the Economy. (ERIC Document Reproduction Service No. ED 341 383)
- Sheingold, K. (1991, September). Restructuring for learning with technology: The potential for synergy. *Phi Delta Kappan*, 73 (1), 17-27.
- Sheingold, K., & Hadley, M. (1990). *Accomplished teachers: Integrating computers into classroom practice*. New York: Bank Street College, Center for Technology Education. (ERIC Document Reproduction Service No. ED 322 900)

- Sheingold, K., & Tucker, M. (Eds.). (1990). *Restructuring for learning with technology*. New York: Center for Technology in Education & National Center on Education and the Economy. (ERIC Document Reproduction Service No. ED 341 383)
- Sivin-Kachala, J., & Bialo, E. R. (1994). *Report on the effectiveness of technology in schools 1990-94*. Interactive Educational Systems Designs. Washington, DC: Software Publishers Association.
- Sokoloff, D. R., Laws, P. S., & Thornton, R. K. (1994/95). *Real time physics: Active learning laboratories mechanics*. Portland, OR: Vernier Software.
- Sokoloff, D. R., & Thornton, R. K. (1990-92). *Tools for scientific thinking motion and force laboratory curriculum and teachers' guide*. Portland OR: Vernier Software.
- Songer, N. B., & Linn, M. C. (in press). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching*.
- Stearns, M. S., David, J. L., Hanson, S. G., & Schneider, S. A. (1991). *Teacher-centered model of technology integration: End of year 3*. Cupertino-Fremont Model Technology Schools Project Research Findings. Menlo Park, CA: Cupertino Union School District CA & Fremont Union High School District CA. (ERIC Document Reproduction Service No. Ed 022 963)
- Strauss, A., & Corbin, J. (1990). *Basics of qualitative research grounded theory procedures and techniques*. Newbury Park: Sage Publications.
- Swan, K., & Mitrani, M. (1993). The changing nature of teaching and learning in computer-based classrooms. *Journal of Research on Computing in Education*, 26 (1), 40-54.
- Thornton, R. K. (1992). Why don't physics students understand physics? *Physics News*, 48-50.
- Thornton, R. K. (1989, September). *Using the microcomputer-based laboratory to improve student conceptual understanding in physics*. Paper presented at the conference, Microcomputer in Physics Education, Cukurova University, Adana, Turkey.
- Thornton, R. K., & Sokoloff, D. R. (1990). Learning motion concepts using real-time microcomputer-based laboratory tools. *American Journal of Physics*, 58, 858-866.

- Thornton, R. K., & Sokoloff, D. R. (1993). *Tools for scientific thinking heat and temperature*. Portland, OR: Vernier Software.
- Thornton, R. K., & Sokoloff, D. R. (1994). *Tools for scientific thinking motion*. Portland, OR: Vernier Software.
- Trumper, R. (1994). Computer assisted teaching of physics. *Journal of Computers in Mathematics and Science Teaching*, 13, 183-195.
- U.S. Congress. (1988). *Power on! New tools for teaching and learning*. Office of Technology Assessment (OTA-SET-379). Washington, DC: U. S. Government Printing Office.
- U.S. Congress. (1995). *Teachers & technology making the connection*. Office of Technology Assessment (OTA-EHR-616). Washington, DC: U.S. Government Printing Office.
- U.S. Department of Education. (1996). *Getting America's students ready for the 21st century: Meeting the technology literacy challenge*. Washington, DC: Author.
- Vernier Software. (1995). *ULI timer (Macintosh version)*. Portland, OR: Author.
- Vicentini, M. (1993). Comment on the article studying conceptual change in learning physics by Dykstra, Boyle, and Monarch. *Science Education*, 77, 713-715.
- Weir, S. (1989). The computer in schools: Machine as humanizer. In Symposium: Visions for the use of computers in classroom instruction. *Harvard Educational Review*, 59, 61-73.
- Woronov, T. (1994, September/October). Six myths (and five promising truths) about the uses of educational technology. *The Harvard Education Letter*, 1-3.
- Yin, R. K. (1993). *Applications of case study research*. Newbury Park: Sage Publications, Inc.
- Yin, R. K. (1984). *Case study research design and methods*. Newbury Park: Sage Publications, Inc.

APPENDIXES

APPENDIX A
NARRATIVE OF PRELIMINARY STUDY

Descriptive Narrative of Preliminary Study

The names of the school, school district, teacher, and students have been changed to preserve the anonymity of all participants. The teacher is referred to as Mr. Max. This is a fictitious name, used for convenience in dialogs. Although four hours of tape was collected in the physics class the narrative will reflect the events of the second period, Physics 1 GT class. The students engaged in two activities during the period, a small group (3 to 4 students) collaborative effort to answer a ten-question evaluation of the Mechanical Universe videotape on simple harmonic motion; and a second collaborative (2 to 3 students) effort to complete one of two possible laboratory experiments, *Simple Harmonic Motion: Pendulum* and *Simple Harmonic Motion: Mass Oscillating on a Spring*. Approximately 20 minutes of the 100 minute period were spent in answering the questions and the remaining portion of the time was devoted to setting-up apparatus and collecting data in the laboratory experiments.

The teacher prepared the students to conduct the lab with opening remarks to clarify written procedures. As he moved to a laboratory set-up consisting of two vertical support bars and a cross bar from which to hang a pendulum from or a mass from, he said, "Hooks Law says I can compress this spring (he demonstrated compression). How do I find the spring constant? This spring hangs to about 15 centimeters with no mass on it at all. I'm using the pole and measuring to the bottom of the tip of the spring. I'm not interested in the length of the spring, I'm interested in the distance the spring stretches. I'll put on a force and measure to the bottom of the spring. It is now 36 centimeters. So

what is the spring constant in Newtons per meter?" One of the students calculates and reports, "23.333333 N/m." The teacher replied, "How many SIG FIGs (significant digits or figures) do I want to have here? I do not want to pretend it is more accurate than it is." They agree on two significant figures, 23 N/m.

The teacher then explained critical points of the pendulum lab. "When I measure the pendulum length, what do I measure? What is the pendulum?" Students responded in unison, "Mass. String. Measure to the same point on the spring." After these clarifying directions, the students went to work first in groups of three to four as they completed the ten question evaluation on simple harmonic motion and then in groups of 2 to 3 on the computers and with the experimental apparatus. The teacher walked around the room with the answers to the ten multiple-choice questions on a sheet of paper. He assessed students in answering the questions by asking other questions to get them to think such as, "What do you think? What is happening here? What happens to the frequency if you change the spring? The stiffer one has a faster slower frequency?" After waiting a short period of time, the teacher answers, "Faster, right?" He then continued, "If the stiffness increases the amplitude decreases, (pause) the natural frequency goes up." The teacher ended this portion of the lesson, collaboratively working on study questions on simple harmonic motion, by collecting the papers and transitioned into the laboratory experiments.

Prior to the arrival of students, the teacher had prepared for the laboratory activities. He installed two upright bars and a horizontal cross support bar on ten lab tables. He assembled materials for the lab --springs, masses, string, and scissors--and

placed them on a cart located in the front of the room. The overhead projection device was connected to the teacher station computer and arranged to project from a centrally placed overhead projector. The boxes of students data disks were placed on a side ledge and on a table at the back of the room. This arrangement of apparatus and disks allowed for less bottleneck of traffic as students began their lab experiments.

Prior to the students moving to the lab set-up, the teacher moved to the front of the room and said, "Briefly OK. Make sure you follow the directions. A couple of things I want to talk on. If you are doing the pendulum, go into the program ULI Vernier Interface to Pendulum. Do you think the graph raw data table will be more valuable? You may find the raw data more valuable. For people doing MacMotion, you will have a velocity, distance, acceleration-time graph. What kind of graph will you end up with?" (pause). A male student responds, "Sine." The teacher repeated the question and again the same student repeated, "Sine." Without recognizing the student, the teacher went to the board and drew a sine wave saying, "You will need to move the cursor to this position (pointing) and go into analyze, get t_1 and t_2 . This is one period, $t_1 - t_2$."

The teacher then held up a spring and said, "If you are doing the spring lab you need to find k." He continued, "If you are using the MacMotion, you will get the period. If you are doing the pendulum you will use the motion timer."

He then took time to explain what the lab report would be and the time period for the lab to be completed. "You will not submit to me a formal lab write-up but you will do a HyperCard stack. The reason is so that the students who did the pendulum will

understand the spring because of the HyperCard stacks. What parts would you have?" The students call out in unison and the teacher reiterates, "Procedure, materials, data, analysis, conclusion."

Teacher, "You will have today, Monday, and Tuesday. When you first started HyperCard, I asked you to submit a written plan since it is more difficult to change the sequence. This time, I will not require it." The teacher then referenced a large book on HyperCard and said, "We are just in the introduction to HyperCard, there is a lot to learn." As a result of the discussion the students knew what was expected of them and how long they had to complete the assignment.

The teacher signaled the end of the discussion with, "Do you have any questions? (pause) OK." The students then transitioned to the lab stations and prepared to do the labs. Students collected apparatus from the front card and disks from the disk caddies. Pendulums were suspended from the cross bars, photogates set in place, and computers started. One student worked at the keyboard and opened the software windows to get to the window for collecting data. The other student worked with the apparatus and set up either a pendulum with a photogate, or a spring and mass system with a motion detector. Both students recorded information in notebooks and read the teacher-prepared handouts with the procedures and questions for the labs.

The teacher moved between working groups of 2 to 3 students answering questions asked by students and asking students questions. Teacher, "What was your question?" Student, "Ours (computer, probe) is not working." Teacher, "It's not. Go to

your window (software screen). What you might have to do, John, is to check these connections.” The teacher checked the connections of the computer, the probe and the ULI (interface box). After making sure that everything was plugged in, the teacher began to check the software. He pointed to the computer screen and said, “I would try to restart it.” John exited the program, restarted the computer, and maneuvered through several screens to get to the point where data could be collected. The teacher worked with the photogate and said, “There is a red light on the bottom of this. If that doesn’t work, move to another station.” Due to some students being absent there were two computers that were not being used during the period. John continued to work with the software and Mary worked with the apparatus until they were able to collect data and a table of acceptable values were recorded.

The teacher was open to not having all of the answers and was able to release control of the class to become a learner along with his students. This was illustrated when a student asked, “Mr. Max is there any way to analyze raw data?” The teacher answered as he looked over the girl’s shoulder and directed her movements, “I think there is. Go to” The problem could not be immediately solved and the teacher said, “I’ll figure this out by Monday, save your data.”

A third episode of trouble-shooting was recorded when two boys were having trouble getting a photogate to work. The boys summoned the teacher, “Mr. Max, we need your help..” The teacher worked with the photogate for a few moments, determined that it was probably malfunctioning and went to the back storage area to retrieve a second

photogate. He connected the new photogate to the ULI and sat down at the computer. After trying several times to collect data, he determined that this unit was not going to work. The two boys went to one of the free computers moving the masses, pendulum, and their books and set-up their experiment again. The teacher continued for approximately 5 minutes to get the computer to work and finally shut the system down and unplugged the computer.

The two boys set up the pendulum and again called to the teacher, “Mr. Max, how do I measure the amplitude?” Mr. Max picked up a meterstick and said, “It is a relative measure, it will be crude. Do it like this.” He measured the position of the pendulum from the rest to the outward position. The boys were delayed for a few minutes but were able to complete the data collection by the end of the period.

The teacher walked around the room for the entire period working with every group several times during the period. Some students he spent a few seconds with and others a few minutes with. As the time for the end of the period drew near, the teacher warned, “Be real careful of the time folks. Put the strings back. Put all of the sets of masses back on the cart and the metersticks too.” Students worked for the entire period and even after the bell rang. Due to the guidance of the teacher, the students were able to collect data and save to disk in preparation for the completion of the lab experiment during the next lab period.

As Marie was leaving she asked, “Mr. Max, how do these disks get infected?” Mr. Max responded, “One of these computers has a virus.” The girl thought for a few minutes

and said, "It has to be that one right there (pointing), since I used it the other day and now my disk has a virus. It is the only computer I have used other than ours."

The teacher called with relief, "Time for lunch!". He had completed two 100 minute periods during which he constantly moved, answered many questions, worked to trouble-shoot apparatus and computer-related technology, and interacted with all students.

Analysis

The data was in the form of notes from interviews, videotapes of two classes that were 100 minutes each, and documents that were collected during the observations. The videotapes were viewed twice by the observer. As the tapes were viewed, a transcription of the audio track and interpretative actions of the teacher and students were recorded in Microsoft Word 6.0. The transcribed notes were edited by viewing the videotapes a second time. A remote control was used to stop, rewind, and play the videotapes. The edited notes were then manipulated and put in the form for Ethnograph to number. The notes from the two videotapes were numbered line by line. They notes were read several times; each time the observer looked for patterns and wrote ideas. The formal codes are just beginning to be added to the notes. Codes were used from the observer's experience in teaching physics and in observing teachers in the formal Teacher Performance Evaluation Program. Terms used also came from Jon Saphier's book, *The Skillful Teacher*.

Interpretation

The School and Teacher of Study

In the initial exploratory study conducted in September, 1994 , seven physics teachers in three high schools were observed. In the narrowing of the study, the researcher videotaped four teachers in two high schools. After transcribing ten hours of videotape, and thinking about various confounding factors such as school size and teacher experience, the study was limited to one teacher in one high school.

The teacher in the study, is an experienced physics teacher who was one of the original pilot teachers in the 1991 district effort to use Macintosh and IBM computers in physics. He is certified to teach earth science and physics. He has been teaching physics at the high school for seven years. He taught Earth Science for five years prior to teaching physics. As a pilot teacher, the teacher was provided with a series of staff development opportunities through Apple Computer and the school district beginning in the Spring of 1991. He participated in Apple-Talk Network Training at Clinton Computer, Stella Training, Macintosh Fundamentals, Probeware Training, HyperCard Training, and Peripheral Use Training. In addition, he participated in Skillful Teacher Training and the Mechanical Universe High School Version Workshop for Physics Teachers. He has also served as a teacher of teachers by teaching the Physics Teachers Computer Training/Curriculum Development Workshop, a forty-hour staff development for all physics teachers as a part of the implementation of physics computer labs in all twenty-plus high schools of the school district. He has taught non college credit courses in

ClarisWorks Word Processor, Database and Spreadsheet, HyperCard for Teachers, and Macintosh Fundamentals. He is an Apple Consultant in Education and has worked in Chesterfield and Gloucester counties, Virginia, and in Phenoxville, PA. He has presented at national conferences including the American Association of Physics Teachers and the National Science Teachers Association.

The high school is one of the smaller high schools in the district with a September, 1994 enrollment of approximately 1100 students. It is located in a suburban area of changing demographics with a student population of 12% Asian, 12% Hispanic, 18% Black, and 58% White. When computers were introduced into the physics program in the 1991-92 school year, the physics enrollment was eighty students; in the 1993-94 school year, the enrollment is one-hundred twenty students, with seven students studying AP Physics. Although AP Physics has been taught in six of the twenty-plus high schools in the district for several years, it was introduced at the school of study in the 1992-93 school year following the second year of the use of computers in physics.

The high school is identified as a special needs school, which means it has a sizable number of students on free or reduced lunches and it has a high number of at-risk students. It has a large English As A Second Language population and offers content classes to beginning literacy students.

Events of interest

In the observation of the teacher's physics classes, several things were evident. The teacher has developed a complex set of skills and knowledge to support the use of

technology in his classes. He has created new laboratory experiments that utilize the computers and he has created student handouts that support these activities. He has learned several software programs including HyperCard, MacMotion, DataLogger, and ClarisWorks. He can troubleshoot these programs and helps students to collect and analyze the data they collect. He has learned to connect all of the probes and computer peripherals and has learned to troubleshoot these as well. He was observed using the motion detector probe and the photogate. The motion detector is a device that sends and receives a signal to detect how far an object is from the probe. The signal is translated into real-time graphs of distance, velocity, and acceleration. The photogate is a light signal timing device. As an object moves through the beam, the computer knows when the gate is blocked and unblocked. Thus, the period of a pendulum can be determined.

The teacher has several skills which make him an effective teacher. He models many concepts to his students. He was observed modeling how to connect the probes to the Universal Laboratory Interface (ULI)--an electronic device that interfaces between the computer and the probes--, how to set up the pendulum, and how to analyze and graph data using the computer software. He clarifies events for students by foreshadowing. During the observation he made statements such as, "You will be working with it under a radical, so you had better make it positive." He peppers his class time with real-world application of the physical principles studied. He talked about building codes in California due to resonance in earthquake zones, resonance in children's swings, and music. He checked back with students while visiting all groups several times during the period. He

checked for clarification; for example he called back from across the room, “Josh, did that fix that (the malfunctioning photogate)?” He assesses students in various ways that are discussed below. He makes long and short range plans for the class. He has adapted to the blocked 100 minute periods in semester classes by creating a long-range schedule of topics and activities to be covered. The students benefit from the skills that the teacher has developed as an instructional leader and a user of instructional technology.

Physical changes have been made in the classroom to accommodate the use of the computers and technology. Tables that were once bolted in place and now free to move and electrical outlets circle the room as well as come down from the ceiling in 12 poles that are located throughout the room. Carts with computers are located adjacent to student work stations which are six foot tables with flat black surfaces. Students sit in pairs at the tables.

The entire room is utilized for collaborative group laboratory activities. The teacher demonstration /lecture desk seems not to be used for lecture purposes since short lecture discussions followed by long periods of student participation in laboratory experiments were observed. The demonstration table has been converted into a teacher desk. Students work in collaborative groups that shift according to the activity, four were observed working on a problem set, and two to three on laboratory experiments.

Several management techniques are evident, the teacher has provided a disk box to store student data disks which students routinely pick up at the beginning of class and deposit at the end of class. He has established classroom routines that utilize technology.

He uses a computer with an overhead projection device and keeps student records on the computer. He uses other related technologies such as the videotape and videodisc. The techniques of questioning students, modeling, and using informational handouts that were emphasized in the Mechanical Universe High School Version Workshop were used by the teacher in both of the classes observed.

Various forms of assessment of student work were utilized. The teacher walked around the room during the entire class period monitoring student work and asking questions. The student report of the laboratory experiments observed were to be written in HyperCard. The collaborative groups worked together to solve a series of multiple choice questions. Students were graded as a group for this activity. Traditional tests are a part of the assessment with a test scheduled for a week or so following the observation.

Conclusion

Four hours of videotape, two informal interviews, and documents have contributed to the initial trial run study of the physics teacher and his classes. The pattern of technology use and classroom interactions of the teacher and students over an extended period of time must be conducted before any conclusive statements can be made with sufficient data to back up the statements. Inferences from the initial data cannot possibly show a pattern, but this trial run study is merely a snapshot of a short period of time in the classroom. The physical filming of the class was an intrusive event that probably affected the behavior of the students and the teacher to some extent. Repeated videotaping may

reduce the effects of having an outside observer with a camera as the students and the teacher interact.

The study can be improved by videotaping consecutive class sessions over a several day period of time. The camera that was stationary and centered in the back of the classroom was better positioned than the hand-held, roving camera to capture activities from a larger number of students. The audio portion of the videotape was difficult to interpret, therefore, in subsequent observations, a small audio tape recorder will be used. A remote microphone will continue to be worn by the teacher that is detected by the stationary camera. The observer will script, using a computer, the entire classroom observation. In the original seven-teacher field study, the observer only scripted the observations; and in the second four-teacher field study, the observer manipulated the stationary camera and used a roving camera. A roving camera should be used sparingly since it seems to be more disruptive to the class than the stationary camera.

Since the high school is on a semester-semester block schedule, the entire study can be conducted in the February to June time frame. New classes of Physics 1 begin February 1, 1995. The observer could begin the study with this new group of students and become more familiar to them than was the observer in the trial run. The study would be over an extended period of time, not just one class period.

A major problem with the initial trial run was that the context of the instructional environment could not be studied. The administration of the school, fellow science teachers, and the greater school staff have been affected by the use of technology in

physics and the leadership that the teacher has shown in the use of technology in the school. Interviews with various groups will be conducted in the study.

Another area for improvement is the transcription, coding and recoding of the data. It will take practice to be able to code data in meaningful ways. The trial run did help the observer to understand better how difficult it is to do a study and how focused and planned the study must be in meaningful qualitative research.

APPENDIX B
CONSENT FORMS

STUDENT CONSENT FORM
Blake High School
1995

You are beginning your study of physics and will have many opportunities this semester to use computers and other technologies in the process of learning. You are invited to become a part of a research study that will help teachers to teach their students using these same technologies. Mr. Max is an experienced physics teacher and has been using computers in his classes since 1990. Other teachers do not have this experience and when they are hired to teach physics in Pace County, they are given the opportunity to learn through special courses. The research from this study will help to plan the staff development for teachers and the videotapes will be edited to use in teacher inservices.

The contents of field notes, notes taken from audio recording and any other information gathered will be available to those working directly with the project. Video and audio recordings and pictures may be used for educational purposes in educational or professional presentations. They may also be used to educate the public about the use of instructional technologies in physics classes.

This research project has been approved, as required, by the Institutional Review Board for projects involving human subjects at the Virginia Polytechnic Institute and State University. You are free to withdraw from this study at any time without penalty or prejudice by contacting your teacher, Mr. Max, or Pat McClure at 698-0400. If you have any further questions, please contact Pat McClure, high school science specialist, at 698-0400.

Your signature below indicates that you have read the information above along with the letter to your parent or guardian and have agreed to participate in this study. You will be offered a copy of this form to keep.

Your signature

Date

March 2, 1995

Dear Parent or Guardian:

I am the district's high school science specialist and a doctoral student in Education at Virginia Tech. As a part of my research and evaluation of the use of computer-related technologies in physics, I will be conducting research in the physics classes of Mr. Max during the second semester.

As students learn physics using computers, I plan to make audio and video recordings of the interactions of the students, the teacher, and the technology. I am also inviting students to further assist in the research by answering interview questions during class about their learning experiences in physics. This research will help us to better understand how students learn physics with the use of computers and how to help new teachers learn instructional strategies for using technology in the classroom.

The video tapes will be edited and selected sections will be used to produce a video for teacher staff development activities.

As was stated in Dr. Kay's letter to the parents in September, video recordings of the district's students is voluntary. Any request you made to the school not to have your child videotaped will be honored. If at any time, your son or daughter wishes to withdraw from the study, they may do so without penalty or prejudice by contacting Patricia McClure.

Please indicate your decision to participate by completing the attached form and returning it to Mr. Mark Johnston, physics teacher at Blake High School, by March 8, 1995. I appreciate your assistance in this research project.

Sincerely,

Patricia H. McClure
secondary science specialist

TEACHER CONSENT FORM
1995-96

Computers and other technologies have been a part of the instructional program in physics since 1990. The classroom environment; personal interactions of students, teachers, and technology; and teaching practice will be researched when computers are a critical part of the instruction.

The contents of field notes, notes taken from audio and video recordings, and any other information gathered will be available to those working directly with the project. Video and audio recordings and pictures may be used for educational purposes in educational or professional presentations. They may also be used to educate the public about the use of instructional technologies in physics classes.

This research project has been approved, as required, by the Institutional Review Board for projects involving human subjects at the Virginia Polytechnic Institute and State University. You are free to withdraw from this study at any time without penalty or prejudice by contacting Pat McClure or Mary Jane at 698-0400, Dr. Tom Gatewood at 698-6043, or Dr. Tom Teates at 703-231-5537. If you have any further questions, please contact Pat McClure, high school science specialist at 698-0400.

Your signature below indicates that you have read the information and have agreed to participate in this study. You will be offered a copy of this form to keep.

Your signature

Date

APPENDIX C
INTERVIEW QUESTIONS

TEACHER INTERVIEW QUESTIONS

1. What barriers to the integration of computers and other technologies into your teaching practice have you encountered? How have they been challenged or overcome? Which ones remain?
2. How has your assessment of student progress changed since computers have been in your classroom?
3. What strategies have you developed for increasing the amount of material covered during the day?
4. What does the computer provide that is unique to the teaching and learning of physics?
5. Do you use students as “experts”? How?
6. How do you use the computer with students? Give examples. How do you use technology in developing curriculum material? Give examples.
7. What would you do without technology in your room?
8. How have you changed the physical environment or re-arranged your classroom and why
9. How has your relationship with your students changed over the last five years, due to the use of instructional technologies?
10. How do you cope with broken equipment? What methods of trouble-shooting have you developed?
11. What training or experiences have been most beneficial to you as a pilot teacher?
12. Do you use the technology resource persons available in FCPS? How?
13. Explain why you have been a leader in restructuring the student day. Why is a 100 minute period important to the use of instructional technologies?
14. Do you consider yourself an adventurous teacher?
15. Explain your personal philosophy of teaching.
16. Have you seen yourself as a learner? Explain.

PRINCIPAL AND ASSISTANT PRINCIPAL INTERVIEW QUESTIONS

The following questions are examples of the type that will be asked.

1. What factors do you believe have contributed to the use of computers in the science program, particularly physics?
2. What support and leadership characteristics do you believe is important in teacher and in administrative staff when innovations are piloted and implemented.
3. How have you utilized support personnel such as technology support people, curriculum specialists?
4. How do you support teachers who are risk-takers? How have you supported your physics pilot teacher?
5. How has the student-day changed as a result of technology use? Has technology use in the classes contributed to you and your staffs' desire to restructure the school day?
6. What barriers do you see to the use of instructional technology? How do you suggest that they can be overcome?
7. What support mechanisms are need in the district to support the use of instructional technologies?
8. What is your personal philosophy of education?
9. How has (the teacher) or other computer-using teachers influenced this school?
10. What do you see as you observe in the classes of computer-using teachers? How has teaching practice changed from your viewpoint?
11. How long do you think it takes to see consistent, frequent, and quality use of instructional technologies once computers and other technologies are in the classroom?
12. What staff development to support technology use have you planned for your faculty?
13. What advice do you have for other administrators or instructional leaders as new technologies are introduced into the classroom?
14. What advice do you have for the technology planners in your district?

APPENDIX D

SAMPLE OF ETHNOGRAPH V4.0 CODE WORD DICTIONARY

TYPE	CODEWORD	PARENT	DEFINITION
Text	STUPREP		Student preparation for physics class or for the advanced classes beyond physics.
Text	LANGUAGEAR	*	Language arts. Evidence that students are learning to write and read technical materials in physics. Writing research papers, synthesizing articles, etc.
Text	MATHPREP	*	Mathematics preparation of students. The mathematical knowledge of the students who take physics.
Text	NO.BARRIER	*	No barriers or things that have proven not to be a barrier such as computers that have not broken down.
Text	ASSESSMENT	ASSESSMENT	Evaluation or assessment of student work, products, or behavior. Products include tests, quizzes, worksheets, homework, lab reports.
Text	CLASSWORK	ASSESSMENT	Classwork is a product of the work done in class that is not a lab report. Maybe a worksheet or product of activity.
Text	HOMEWORK	ASSESSMENT	Students are expected to complete homework problems or readings.
Text	LABREPORT	ASSESSMENT	Students are expected to have evidence of a completed lab in the form of graph, answers to questions, or a formal lab report.
Text	NOTEBOOK	ASSESSMENT	Students taking notes in notebooks. This is used in problem solving and is expected by the teacher.
Text	QUIZ	ASSESSMENT	Students are quizzed on materials they have studied, videos they have viewed etc.
Text	TEST	ASSESSMENT	Students are tested on materials they have studied.
Text	WHATSDUE	ASSESSMENT	Students ask each other and the teacher what is expected to be turned in for a grade. They frequently did not know exactly what to turn in--a formal write up, answered questions, spreadsheets, graphs, etc to make up a lab report.

TYPE	CODEWORD	PARENT	DEFINITION
Text	AIRCONDITI	BARRIER	Non-airconditioned buildings or rooms were initial barriers to the use of computers. Facility barrier.
Par	BARRIER	BARRIER	A barrier is anything that inhibits the use of technology in instruction. Barriers have been identified in all transcribed tapes of instruction and interviews. Included are time, money, wait time, etc.
Text	ELECTRICAL	BARRIER	Electrical wiring or lack thereof is a barrier to the use of computers in older classrooms. Frequently electrical circuits and/or outlets have to be added to classrooms.
Text	EXTRACOMPU	BARRIER	Extra computers or hardware to use when something breaks down. It is a support when it exists and a barrier when it does not. Frequently computers or printers are taken to be repaired and there are no replacements.
Text	FACILITY	BARRIER	Facility or physical plant or room. Frequently the size of the room, location of the room, wiring in the room, or other aspect of the physical environment is a barrier to the use of instructional technology.
Text	LABINSTCFN	BARRIER	Confusion caused by inadequate or unclear written directions to the laboratory activity. Errors in procedure or instruction sheets.
Text	LACKOFHDWR	BARRIER	Lack of hardware or equipment was given as a barrier to the use of instructional technology.
Text	MISMATCH	BARRIER	Mismatch between the software and hardware so that people are unable to do a task such as Clairisworks not working on Apple IIe computers. This incorporates the idea of upgrade also.
Text	MONEY	BARRIER	Lack of money or funding was given as a barrier to the use of instructional technology. Allocation of funds to other things is also included. Finding money to purchase computers and software, change electrical wiring etc was administrative

TYPE CODEWORD	PARENT	DEFINITION
Text NETWIRING	BARRIER	Network wiring. Buildings were not wired for a building-wide network in which all computers can communicate with each other. Buildings are being wired. This barrier will be changing to a support when that happens.
Text NO.OF.COPY	BARRIER	The number of copies of software that can be purchased. A barrier can be when schools do not have a legal number of copies of software. Copyright issues.
Text NONETWORK	BARRIER	No network or backbone network, wiring within and to the outside. Wiring that allows computers to communicate with other computers within and outside of the building.
Text NOTALLUSE	BARRIER	Not all teachers use the technology available or take advantage of the staff development opportunities.
Text PLAN.TIME	BARRIER	Time to plan. Can be a barrier but is now a support with the restructured day. The teachers have a solid 90 minute period to plan every day.
Text PROBGRAPH	BARRIER	Any problem in graphing data.
Text PROBHARDWR	BARRIER	Any hardware problem. Could be memory problem or cables not being plugged in. This does not include probeware.
Text PROBMEMORY	BARRIER	Problems with lack of memory in computers. Crashes occur or "bomb" appears and students have to start over.
Text PROBPRINT	BARRIER	Problems with printing.
Text PROBSAVE	BARRIER	Any problem in saving data or work on the computer.
Text PROBSS	BARRIER	Problems with spreadsheets such as not knowing how to enter equation in cells, how to access the spreadsheet, or how to add or delete data.
Text SOFTWRCOST	BARRIER	Software cost. The high cost of software has been seen as a barrier to the use of instructional technology and a problem that is associated with copyright laws.

TYPE	CODEWORD	PARENT	DEFINITION
Text	TIME	BARRIER	The time for teachers to learn to use new machines or software, to create lessons that use new products. Lack of time to learn software and how to use it with students has been a major barrier. Administrators can support teachers by providing time
Text	UPGRADE	BARRIER	The idea that software and/or hardware must be replaced with new versions come out. Sometimes old machines will not run new software. Sometimes old software is no longer useful.
Text	USERFRIEND	BARRIER	User friendly. The idea of having software and/or hardware that can be easily used by people because it is created with people in mind and not technocrats.
Text	WAITTIME	BARRIER	Time required for students to wait to receive help from teacher.
Text	WHOSNCHARG	BARRIER	Who is in charge? The idea that when technology was first introduced no one department was clearly in charge of support. It was difficult to know who to call when there were problems.
Text	WIRING	BARRIER	The schools were not wired for computer use and the wiring of the schools had to be planned, funded, and implemented over a series of years. Network wiring of old buildings is a barrier to the use of technology in some ways.
Par	BELIEF	BELIEF	Belief is the expressed beliefs of teachers and administrators about teacher characteristics or advantages of computer use in instruction. Beliefs may or may not be factual.
Text	APPHYSICS	BENEFIT	Advanced Placement Physics (AP Physics) is a second level college class that was added at the school as a result of increased enrollment of juniors in physics and interest of students.
Par	BENEFIT	BENEFIT	Benefits are advantages of using technology in instruction. Benefits of having computer labs in physics, in the school. Benefits may be to teachers, schools, students, etc.

TYPE	CODEWORD	PARENT	DEFINITION
Text	COMHELPLRN	BENEFIT	Computers help students to learn a skill or concept. This belief was held by teachers and administrators.
Text	CONDIFENCE	BENEFIT	Students or teachers express confidence in what they are doing involving the use of technology in the classroom.
Text	CREATIVE	BENEFIT	Evidence of students using their brains to create something new or present knowledge in new and interesting ways.
Text	ENROLLMORE	BENEFIT	More students have enrolled in physics at the school studied. A benefit that was given by everyone interviewed.
Text	KIDSFIRST	BENEFIT	The idea of having technology first for student use. To place students (kids) at the center of the educational enterprise. Keeping the main thing the main thing. This could be TECHUSE, PHILOSOPHY, BENEFIT, TSTRATEGY
Text	MOREKIDS	BENEFIT	Morekids is the idea of having students enrolled in physics who would not have ordinarily taken physics. Giving opportunities to more students to take physics.
Text	NEWSKILLS	BENEFIT	Skills that students and teachers previously did not have such as ability to word process, create and use spreadsheets, create graphs and analyze data using graphing and statistics programs, analyzing large data sets for patterns and validity, etc.
Text	OLDTONEW	BENEFIT	Evidence of change from the OLD way of doing things to NEW ways. This was given in many contexts but mostly the way concepts in physics are taught.
Text	REALSCIENC	BENEFIT	Students and teachers talk about real science or real physics. Usually refers to experimentation with real world applications and data that is meaningful to students.
Text	SCI.FAIR	BENEFIT	Science Fair. Local, Regional, and International Science Fair. Students use instructional technology to collect data, graph data, and create presentations.

TYPE	CODEWORD	PARENT	DEFINITION
Text	SCONTRLLRM	BENEFIT	Evidence of students taking control of their learning.
Text	STUEXCITMT	BENEFIT	Evidence of student excitement in the learning process.
Text	SUCCESS	BENEFIT	Success in the learning process.
Text	SVALUETECH	BENEFIT	Students value the technology and come to depend on its use in the classroom. They are upset when the technology does not function right or the power is off.
Text	TVALUETECH	BENEFIT	Teachers value technology and express the need for it to the point of paying for things themselves or teaching only where there is technology.
Text	WORDPROCES	BENEFIT	Word process is a skill that students and teachers use to create documents. Students now come to the physics classroom with this skill and have used it in several previous classes.
Text	PHYTCOMRAD	COMRADE	Physics teacher comrade. A physics teacher to collaborate with.
Text	SWORKEXTRA	ENTHUSIASM	Evidence of students coming in before school, after school, during other classes to work on physics. Indicative of interest or enthusiasm to complete projects in physics.
Par	FUTUREPLAN	FUTUREPLAN	The ideas presented that should formulate the plans for the future. Ideas for staff development, restructuring the school day, school-based management, instructional technology, etc.
Text	SLEADER	GROUPDYNAM	Student leader within a group directs others in tasks to be completed.
Text	HELPSUMRY	INTERACT	Summary of the help that the teacher gave to the student(s). Problem is stated and time of interaction is included.
Text	TIMEOFHELP	INTERACT	Time of the teacher-student interaction.
Text	GROUPSIZE	MANAGEMENT	Number of students in working groups.
Text	HLPTIMEMGT	MANAGEMENT	Method of time management to assist students in class.

TYPE	CODEWORD	PARENT	DEFINITION
Text	MANAGEMENT	MANAGEMENT	Management refers to the way in which a teacher organizes, plans for and manages learning and the learning environment.
Text	RATIO.C.ST	MANAGEMENT	Ratio of computer to students that is used in physics. Usually one computer per 2 to 3 students.
Text	RESOURCE	MANAGEMENT	Resource refers to a variety of things that are used to teach students such as texts, articles, research data bases, instructional technology (including simulation and utility software, probeware), etc. The teacher manages resources.
Text	ROOMARRANG	MANAGEMENT	Room arrangement. The arrangement of tables, computers, carts, printers, desks, etc. within the room for the most efficient use of the space.
Text	ROUTINE	MANAGEMENT	Routine. The establishment of a routines or patterns of behavior expected by teachers. Routines include ways of doing things such as the way students keep records on data disks, collect and return apparatus for experimentation, ask for help, etc.
Text	SPACE	MANAGEMENT	Space. The physical room or space where learning occurs. This can be a barrier but it is something the teacher must manage.
Text	TORGANIZAT	MANAGEMENT	Evidence of teacher organization such as files of xeroxed papers, disks in place, homework posted, grades posted.
Text	LIFELEARS	PHILOSOPHY	Philosophical idea that people are life long learners.
Par	PHILOSOPHY	PHILOSOPHY	The personal philosophy or belief system ... used in these documents for philosophy of education.
Text	BIGGLITLG	PHYSICS	Distinguish between g--acceleration due to gravitational force and G--universal gravitational constant, a common source of confusion for physics students.
Text	CENTPFORCE	PHYSICS	Study of or reference to centripetal force in lecture discussion or lab activity.

TYPE CODEWORD	PARENT	DEFINITION
Text CURRICULUM	PHYSICS	Any reference to the program of studies, curriculum, lesson plans etc. to teach students physics.
Text EXPTDESIGN	PHYSICS	Reference to experimental design, variables, and controls.
Text GRAVITFORC	PHYSICS	Discussion of or reference to gravitational force.
Text MATH	PHYSICS	Evidence of math being taught or discussed in physics classes
Text ORBVELOCIT	PHYSICS	Orbital velocity of a planet or satellite.
Text PAPPPLICATN	PHYSICS	Practical application or real world application of physics concepts/ principles.
Par PHYSICS	PHYSICS	Anything that refers to physics content or the processes of science associated with the teaching of physics.
Text PSSC	PHYSICS	A text and physics curriculum used in Physics 1 Gifted and Talented classes in the district.
Text UNIT	PHYSICS	The use of units such as m/s.
Text UNITS	PHYSICS	Discussion of or reference to the units of quantities common in physics such as meter, kilogram, Newton etc.
Text VELOCITYAC	PHYSICS	Velocity and acceleration. Evidence of concepts of velocity and acceleration being taught in physics.
Text VOCABDEFIN	PHYSICS	Evidence of students learning physics terms/vocabulary. Defining meaning of words used in physics.
Text CONFUSION	PROBSOLVIN	The expression of confusion in trying to solve a problem.
Text DATAANALYS	PROBSOLVIN	Evidence of students analyzing data for patterns.
Text GRAPHANALY	PROBSOLVIN	Analysis of graph.
Text PROBSOLVIN	PROBSOLVIN	Problem solving. Evidence of students solving problems in the use of technology or mathematical problems, or other challenging questions in the classroom.

TYPE	CODEWORD	PARENT	DEFINITION
Text	PSASKSTUDT	PROBSOLVIN	Problem solving -- when student asks a fellow student or a fellow student helps others in solving problems.
Text	PSASKTEACH	PROBSOLVIN	Problem solving--when students asks the teacher for help.
Text	PSDEFPROB	PROBSOLVIN	Problem solving--defining the problem. Stating the problem in clear terms.
Text	PSGATHMAT	PROBSOLVIN	Problem solving--when students gather materials to help with the solution, for example notes from class, data, printouts, lab instruction sheets, etc.
Text	PSNOTES	PROBSOLVIN	Problem solving--students use their notes from class in the search for a solution.
Text	PSPULLMENU	PROBSOLVIN	Problem solving--students use the pull down menus on the software to search for answers or keys to how to solve the problem.
Text	PSQUESDATA	PROBSOLVIN	Problem solving--students or teacher question data accuracy or validity.
Text	PSREAD	PROBSOLVIN	Problem solving--students read the text, notes, or lab instruction sheets to get clues to how to solve the problem.
Text	PSSDEFPROB	PROBSOLVIN	Students defing the problem to be solved.
Text	PSSEXPLAIN	PROBSOLVIN	Students pose possible explanation for problem.
Text	PSTDEFPROB	PROBSOLVIN	Problem solving--teacher defined the problem.
Text	PSTRIALERR	PROBSOLVIN	Evidence of students solving problems by trial and error. Try it first and see if it works.
Text	SPLITGROUP	PROBSOLVIN	Splitting up groups when a piece of equipment fails or the groups are not or cannot function.
Text	TROUBLESHO	PROBSOLVIN	Trouble shooting a problem solving technique in which students and/or the teacher looks for problems in software or hardware by a process of elimination.

TYPE	CODEWORD	PARENT	DEFINITION
Text	TEXT	RESOURCE	Textbooks. Several people commented on the changing role of textbooks in learning. The idea of a textbook per child or text-centered education is changing with technology.
Text	ADMINSUPP	SUPPORT	Administrative support. Evidence of administrative support to the teacher in the use of technology.
Text	APPLE	SUPPORT	Apple Computer Inc. was an initial supporter of the use of technology in schools. Hardware and training was initially given to pilot schools. Later company was of less help.
Text	CHANGEAGNT	SUPPORT	Change agents are people who facilitate change. They may be teachers, school administrators, or central staff. Someone who believes in and facilitates change.
Text	CLASSCOVER	SUPPORT	Class coverage is when administrators or department chairs or fellow teachers take over the role of the teacher to allow the teacher to have time to do other things such as learn to use the technology.
Text	COMRADE	SUPPORT	The idea of having someone to share with to learn from. The idea of collaboration among colleagues, cohesiveness of schools or departments. To work together for the common good.
Text	CSTAFF	SUPPORT	Central personnel (staff) or organization that supports the planning and implementation of instructional technology. Central may be facilities planners, maintenance people, technical hardware/software support staff, curriculum supervisors.
Text	DEPTCHAIR	SUPPORT	Science department chairpersons support the use of technology using teachers by prioritizing budget to obtain supplies for tech use such as disks, printer paper, etc. Also working with school and central administrators to obtain hardware/staff dev.
Text	ENCOURAGE	SUPPORT	Evidence of teachers being encouraged to change the way they teach students using instructional technologies or new methods.

TYPE CODEWORD	PARENT	DEFINITION
Text HOLISTIC	SUPPORT	Holistic planning of the use of technology can be a support. The lack of a good plan that considers all resources and potential uses can be a barrier.
Text LISTEN	SUPPORT	Idea of administrator that listening to teachers and hearing what they are saying about technology or other change helps or supports the teachers.
Text OPENDOOR	SUPPORT	The idea of having an "open door" policy in allowing teachers to come in anytime to discuss anything with the administrator.
Text PLANHOLSTC	SUPPORT	The idea of planning holistically. This should be a support but may be a barrier if this is not done. The applies to district planning as well as school planning for the use of instructional technology. THE BIG PICTURE.
Text RESPECT	SUPPORT	Respect. Teachers referred to administrators respecting their knowledge and judgement. This was associated with administrative support.
Text RESTRUCTDA	SUPPORT	Restructured day. The school in the study has a restructured day which supports the use of technology in the school.
Text SCHBASEMGT	SUPPORT	School based management is the idea of having more decisions made on the school level and less centrally. This especially applies to the expenditure of money to purchase resources for students to use in the learning process.
Text SCHORGANIZ	SUPPORT	School organization. The structure, committees, or methods of conducting business within a school. The organization of the school to support the use of instructional technology.
Text STAFFDEV	SUPPORT	Staff development. Sometimes referred to as training. The idea of providing a means for teachers to learn new skills or content through courses or other means.
Text STUEXPERT	SUPPORT	Students can become experts and assist the teacher in working with hardware or using software.

TYPE CODEWORD	PARENT	DEFINITION
Par SUPPORT	SUPPORT	Evidence of anything or person that contributes to the implementation of the use of instructional technology.
Text TECHNICAL	SUPPORT	Technical support such as repair and maintenance of hardware by district maintenance facilities personnel.
Text TECHPLAN	SUPPORT	Technology plan for the use of computers or other technologies. Can be a local school plan or committee or a district plan. It supports the use of technology by serving as a guide for the implementation and full utilization of resources.
Text VERNIER	SUPPORT	Vernier is a software and probeware company that produces sensors for use in science classrooms, especially physics classrooms. Vernier provides technical support for all products and has been reliable and available for teachers.
Text COMFORTLVL	TCHARACTER	Comfort level is the an indication of degree to which a person is willing to feel not in control.
Text DYNAMIC	TCHARACTER	Dynamic or constantly changing or improving instruction or curriculum.
Text EMPATHY	TCHARACTER	Empathy or identification with the struggles that children go through in learning. Especially in learning new skills and content.
Text GIVEUPCNTL	TCHARACTER	Give up control. The idea that the teacher is not longer the giver of all knowledge and gives up the tight control of the class to allow students to be move responsible for their own learning.
Text INITIATIVE	TCHARACTER	Initiative is the idea of taking control of one's destiny ... taking the first steps to making something happen or change. To orginate without being asked to do so.
Text INVITING	TCHARACTER	Inviting or creating an environment in which people are welcome to come and learn. An inviting classroom is one in which students feel free to express themselves and try things. This seems more of a teacher characteristic to me than anything else

TYPE CODEWORD	PARENT	DEFINITION
Text KNOWITALL	TCHARACTER	Know it all. The feeling that one has to know all of the answers and be in control. Related to comfort zone or comfort level.
Text LEADER	TCHARACTER	Evidence that the teacher of technology is a leader in the school and/or county.
Text MENTOR	TCHARACTER	Evidence that the technology using teacher is a mentor to others.
Text NEWHORIZON	TCHARACTER	New horizons or visions of new ways of using technology in the classroom such as the use of the Internet to communicate with scientists and other students, to share data, and to access information.
Text NONTRADITN	TCHARACTER	Nontraditional was used to describe teachers who are willing to try new things. The idea of breaking with the way things have always been taught.
Text PGROWTH	TCHARACTER	Personal growth. The idea of having a vision or goal of what a person wants to learn or advance in knowledge.
Text SELFIMAGE	TCHARACTER	Self image or the way teachers describe themselves.
Text TADMITNK	TCHARACTER	Teacher admits to not knowing everything.
Text TCHARACTER	TCHARACTER	Characteristics of teachers, particularly technology using teachers.
Text TEXCITEMNT	TCHARACTER	Teachers are excited or indicate that they really like to use technology.
Text TEXPECT	TCHARACTER	Teacher expectations of students in homework, classwork, behavior, student progress. This is a characteristic of teachers ... they have expectations for student behavior.
Text TEXTRAWORK	TCHARACTER	Teacher extra work. The use of technology requires extra work in the summer, after school, and before school to learn the programs and integrate it into the curriculum.
Text TLEADER	TCHARACTER	
Text WILLNCHANG	TCHARACTER	Willingness to change. The idea of a willingness or a wanting to change the way one teaches or does something.

TYPE CODEWORD	PARENT	DEFINITION
Text DATAENTRY	TECHUSE	Data being entered by students into a software program.
Text DATARECORD	TECHUSE	Recording simulation data to a spreadsheet using the icons in the program.
Text GOODHRDWR	TECHUSE	Good hardware or the advantages of having software or hardware was given as a reason that teachers and students use the computers in physics for other purposes.
Text HARDWARE	TECHUSE	Hardware refers to computers, printers, scanners, monitors, and sometimes interfacing apparatus used in the physics classroom.
Text INTERFACIN	TECHUSE	Interfacing or probeware. The use of probes or sensors to measure physical phenomena. Interfacing in physics involves many probes including motion detectors, force sensors, smart pulleys, photogates.
Text INTERNET	TECHUSE	Internet is a way of communicating with other computers outside of the building. It is a pathway.
Text MOTIONDECT	TECHUSE	Motion detector. A probe used to measure the distance an object moves. It reports out distance-time, velocity-time, and acceleration-time.
Text PRESENTAT	TECHUSE	The idea of using technology to produce documents or materials that are "professional quality." The idea of pride in the products turned in or used for presentations. Maybe homework, lab reports, overheads, handouts. etc... products.
Text PRINTER	TECHUSE	Printers used in the classroom to support the use of software.
Text PRINTOUT	TECHUSE	Print out of a graph or data table or word processed document. Any thing printed on printer paper.
Text SCOMPUTUSE	TECHUSE	Evidence of students using computer lab for other classes...coming in to work on computers when they are not in the actual physics class.
Text SDISK	TECHUSE	Evidence of student's using disks they supply.
Text SMARTPULLE	TECHUSE	Smart pulley. A probe or sensor used to time a falling object that is connected to a pulley mechanism.

TYPE	CODEWORD	PARENT	DEFINITION
Text	SOME.OK.NO	TECHUSE	The idea that some things that were tried and not in practice because it did not meet the needs of the instructional program or did not work properly. Some of the pilot software was not expanded to all schools because it was not used.
Text	SPREADSHET	TECHUSE	Spreadsheet. The use of spreadsheets either within the simulation or in a separate program to manipulate data prior to graphing them.
Text	TCOMPUTUSE	TECHUSE	Evidence of other teachers using the computers in physics for word processing, telecommunicating, etc.
Text	TECHCALCUL	TECHUSE	Evidence of the use of calculators in physics. Technology use is calculators.
Text	TECHCBL	TECHUSE	Use of the calculator based laboratory (CBL) with the graphing calculator. This device can connect to probes and can be used to collect data that can be graphed on the calculator or exported to a computer.
Text	TECHLABAPP	TECHUSE	Evidence of the use of laboratory apparatus such as carts, motors, oscilloscopes, pendulums, etc.
Text	TECHPROBEW	TECHUSE	Evidence of the use of probeware in physics. Technology use is probeware.
Text	TECHSIMULA	TECHUSE	Evidence of the use of computer simulations in physics.
Text	TECHSOFTWR	TECHUSE	Title of a piece of software.
Text	TECHUSE	TECHUSE	The use of technology in the classroom. Technology includes software such as simulations, probeware, hardware such as printers, videodisc players, videotape players, etc.
Text	TECHVIDEOD	TECHUSE	Evidence of the use of videodiscs in physics.
Text	TECHVIDEOT	TECHUSE	Evidence of the use of videotapes in physics. Technology use is videotapes. Mechanical Universe High School Adaptation--MUHSA videotapes or others.

TYPE	CODEWORD	PARENT	DEFINITION
Text	ALLEARN	TEXPECT	All students are expected to learn. Evidenced by knowing how to do calculations or answer questions for themselves.
Text	DISCIPLINE	TEXPECT	All students are expected to be disciplined in class and to pay attention. The teacher will take action to enforce proper behavior of students.
Text	NOTETAKING	TEXPECT	Teacher expects students to take notes and use them for tests, quizzes, or laboratory activities.
Text	PAYATTENTN	TEXPECT	Teacher expects students to pay attention in class and actively participate.
Text	SATTENTION	TEXPECT	Teacher expects students to pay attention during class discussions, films, lab etc.
Text	STHINK	TEXPECT	Students are expected to think and to answer some of their own questions.
Text	WORKINCLAS	TEXPECT	The teacher expects all students to work in class during the entire period.
Text	COLABLEARN	TSTRATEGY	Collaborative or cooperative learning is a strategy for placing students together in a learning environment in which they learn from each other. Students under teacher direction share in the learning process.
Text	CUSTOMHELP	TSTRATEGY	Customized help in the learning process. The idea students getting help from the teacher. Giving more help to those who need it and encouragement to those who can learn more quickly.
Text	FACILITATE	TSTRATEGY	Facilitator or one who facilitates learning. The idea of an orchestra of resources. Planning and gathering information and materials for students to use in learning. Creating a learning environment.
Text	FORSHADOW	TSTRATEGY	Teacher forshadows what will happen in the future.
Text	KNOWSTUDT	TSTRATEGY	Knowing what students need or who they are as people. By knowing students teachers can better prepare to teach students by creating learning environments customized for the student(s) needs.

TYPE	CODEWORD	PARENT	DEFINITION
Text	LEARNSTYLE	TSTRATEGY	Learning styles. Knowing about and providing for the learning styles of students--visual, auditory, and tactile/kinesthetic.
Text	PLANS	TSTRATEGY	The idea that teachers must plan, plan, plan to use technology in the class. It requires more planning than before and fits in to the teacher as facilitator of learning.
Par	PREDICT	TSTRATEGY	Teacher asks students to predict what will happen. Students think about possible outcome.
Text	RECALL	TSTRATEGY	Teaching strategy--teacher asks students to recall previous learning.
Text	SANSWER	TSTRATEGY	Students answers a question.
Text	SCOLABORAT	TSTRATEGY	Students collaborate in the learning experience. They discuss or share information with lab partners.
Text	SCRITQUES	TSTRATEGY	Students ask critical questions that will help them to understand a concept or continue in the learning process.
Text	TASKSTHELP	TSTRATEGY	Teacher asks students to help fellow students.
Text	TAVOIDCONF	TSTRATEGY	Teaching strategy of pointing out confusing steps or highlighting areas of common problems or misconceptions.
Text	TCONTOABST	TSTRATEGY	Teaching strategy of presenting concept in concrete terms and then moving to the abstract.
Text	TCRITQUES	TSTRATEGY	Teacher asking critical question to clarify student question or problem.
Text	TDIRECTCOM	TSTRATEGY	Teacher directly giving computer commands such as EDIT, COPY, Press RETURN, etc.
Text	TGUIDANCE	TSTRATEGY	Teaching strategy--degree of guidance. The idea is to decrease the guidance as the students progress.
Text	TLECTDISCN	TSTRATEGY	Lecture and interactive discussion with students activley participating.

TYPE	CODEWORD	PARENT	DEFINITION
Text	TMODELING	TSTRATEGY	Teaching strategy of the teacher demonstrating a lab technique or modeling how to perform a calculation.
Text	TMONITOR	TSTRATEGY	The teacher monitors student progress by walking up and down the aisles, looking at computer screens, or student work.
Text	TPERSONALM	TSTRATEGY	Teaching strategy of giving an example that will have personal meaning to the students.
Text	TPRAISE	TSTRATEGY	The teacher praises students for good work or correct answers. This is a teaching strategy and evidence of human relations.
Text	TQUESTANSW	TSTRATEGY	Teacher asks questions, students answer, teacher repeats answer and asks another question.
Par	TSTRATEGY	TSTRATEGY	Teaching strategy. A method or idea that teachers use to teach students.

APPENDIX E
RESOURCES USED IN PHYSICS CLASSROOM

Table 9.

Software Resources in Classroom

Software Title	Publisher	Description
Graphical Analysis	Vernier Software	Software graphs and statistically analyzes data input from the keyboard or from other programs.
ULI Timer	Vernier Software	Software graphs or displays data in table form for timing devices such as the Smart Pulley.
Motion	Vernier Software	Software graphs or displays in data tables data that are collected with the motion detector.
Temperature	Vernier Software	Software displays data tables and graphs data from temperature probes.
Data Logger	Vernier Software	Software displays data tables and graphs from data collected with the force sensor and magnetic field sensor.
Physics Explorer: Gravity	Logal Educational Software	Software simulates the motion of a body in a gravitational field of a massive fixed body.
Physics Explorer: Harmonic Motion	Logal Educational Software	Software simulates the oscillating of a single mass about an equilibrium position.
Physics Explorer: Waves	Logal Educational Software	Software simulates the motion of transverse waves along a spring with point masses.
Physics Explorer: Diffraction and Interference	Logal Educational Software	Software simulates diffraction-interference patterns by coherent source.
Physics Explorer: AC/DC Circuits	Logal Educational Software	Software simulates a 3-branch series and parallel electric circuit with common electrical measurements.

Table 9. (Continued)

Software Resources in Classroom

Software Title	Publisher	Description
Physics Explorer: Ripple Tank	Logal Educational Software	Software simulates a two-D wave within a tank created by a point or line source.
Interactive Physics II	Knowledge Revolution	Interactive simulation software that allows students to create experiments and manipulate variables. Multiple data displays are available to students.
Interactive Physics II Simulations	Addison-Wesley	Package consists of 32 simulations and printed materials based on Interactive Physics Player software. Students cannot create environments but can input variables.
At Ease	Claris	A computer management software that enables the teacher to control access to the computer control panel and applications.
HyperCard	Claris	Presentation hypertext program that allows students to create an electronically linked presentation with graphics and text.
ClarisWorks for Macintosh	Claris	Integrated utility package that consists of word processor, database, spreadsheet, drawing, paint, presentation, and communications.
CA Cricket Graph III	Computer Associates	Graph ultiity software that graphs and statistically analyzes data.

Table 10.

Videodisc Resources in Classroom

Title	Publisher	Description
Cinema Classics	Z-Tech	A series of movie clips from the original PSSC films and other demonstrations of physics concepts. Produced by American Association of Physics Teachers.
Physical Science	Optical Data	Movie clips and stills that illustrate many chemistry and physics principles. Better suited for middle school.
Physics of Sports	Videodiscovery	Movie clips and stills of sporting events. Students can collect data on a TV screen.
The Tacoma Narrows Bridge	Wiley and Sons	A movie of the collapse of the Tacoma Narrows Bridge. Physics principles are discussed.

Table 11.

Textbook Resources for Students: Class Sets of High School Physics Books

Author	Title
Haber-Scham, Dodge, & Walker	<u>PSSC Physics</u>
Hewitt	<u>Conceptual Physics</u>
Hickman	<u>Problem Solving Exercises in Physics</u>
Martin	<u>PhysicAL</u>

Table 12.

Textbook References for the Teacher

Author	Title
District	<u>Physics 1 Computer Curriculum Handbook (DRAFT)</u>
District	<u>Physics 1 Program of Studies</u>
Laws, Boyle, Luetzelschwab, Sokoloff, & Thornton	<u>Workshop Physics II Activity Guide</u>
Sokoloff, Laws, & Thornton	<u>Real Time Physics: Active Learning Laboratories Mechanics</u>
Thornton, & Sokoloff	<u>Tools for Scientific Thinking Heat and Temperature</u>
Thornton & Sokolof	<u>Tools for Scientific Thinking Motion</u>

Table 13.

Probeware Resources in Classroom: Probeware Sold by Vernier Software

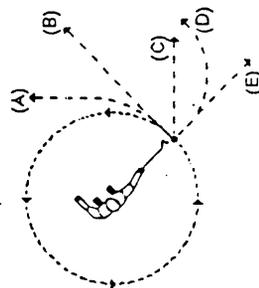
Probe	Description
Low g Accelerometer	A ± 50 m/s ² accelerometer that is good for cars and amusement park rides.
Motion Detector	Sonar device that emits ultrasonic pulses at 10 to 50 times per second. From return time on reflected surfaces distance, velocity, and acceleration is calculated and displayed in graphs and data tables.
Pasco Smart Pulley	A ten spoke timing device that works in conjunction with ULI Timer software. As pulley rotates the photogate beam is alternately blocked and unblocked by the pulley spokes. These signals are relayed to the computer for timing and processing.
Pasco Photogate	A device that times motion of an object as it passes through a gate with light emitting diode on one side and light sensor on the other.
Student Force Sensor	Strain gage force measurement device that can measure forces from 0.05 to 10 N.
Microphone	Electric microphone with amplifier circuit in a box that allows students to study wave forms of voice and music sounds.
Temperature Probe	Direct-connect temperature probe is Teflon-coated brass tube with sensor that measures -15°C to 110°C.
Magnetic Field Sensor	Sensor uses a Hall Effect transducer to measure magnetic fields in 2 ranges, $\pm 3.2 \times 10^4$ tesla and $\pm 6.4 \times 10^{-3}$ tesla.
Light Sensor	Sensor mimics human eye in spectral response and can be used for inverse square law and solar experiments. 0-150,000 lux.

APPENDIX F
FORCE CONCEPT INVENTORY

Reprinted with permission from Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*, 30, 141-153. American Association of Physics Teachers.

Force Concept Inventory

- Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two story building at the same instant of time. The time it takes the balls to reach the ground below will be:
 - about half as long for the heavier ball.
 - about half as long for the lighter ball.
 - about the same time for both balls.
 - considerably less for the heavier ball, but not necessarily half as long.
 - considerably less for the lighter ball, but not necessarily half as long.
- Imagine a head-on collision between a large truck and a small compact car. During the collision,
 - the truck exerts a greater amount of force on the car than the car exerts on the truck.
 - the car exerts a greater amount of force on the truck than the truck exerts on the car.
 - neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
 - the truck exerts a force on the car but the car doesn't exert a force on the truck.
 - the truck exerts the same amount of force on the car as the car exerts on the truck.
- Two steel balls, one of which weighs twice as much as the other, roll off of a horizontal table with the same speeds. In this situation:
 - both balls impact the floor at approximately the same horizontal distance from the base of the table.
 - the heavier ball impacts the floor at about half the horizontal distance from the base of the table than does the lighter.
 - the lighter ball impacts the floor at about half the horizontal distance from the base of the table than does the heavier.
 - the heavier ball hits considerably closer to the base of the table than the lighter, but not necessarily half the horizontal distance.
 - the lighter ball hits considerably closer to the base of the table than the heavier, but not necessarily half the horizontal distance.



- A heavy ball is attached to a string and swung in a circular path in a horizontal plane as illustrated in the diagram to the right. At the point indicated in the diagram, the string suddenly breaks at the ball. If these events were observed from directly above, indicate the path of the ball after the string breaks.

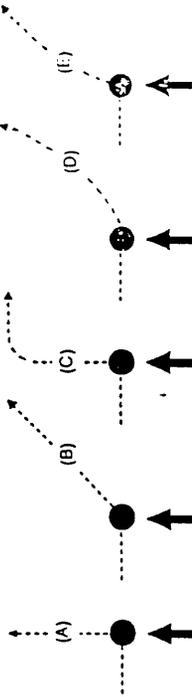
- A boy throws a steel ball straight up. Disregarding any effects of air resistance, the force(s) acting on the ball until it returns to the ground is (are):

- its weight vertically downward along with a steadily decreasing upward force
- a steadily decreasing upward force from the moment it leaves the hand until it reaches its highest point beyond which there is a steadily increasing downward force of gravity as the object gets closer to the earth.
- a constant downward force of gravity until the ball reaches its highest point, after which there is only the constant downward force of gravity.
- a constant downward force of gravity only.
- none of the above, the ball falls back down to the earth simply because that is its natural action.

- Use the statement and diagram below to answer the next four questions:
- The diagram depicts a hockey puck sliding, with a constant velocity, from point "a" to point "b" along a frictionless horizontal surface. When the puck reaches point "b", it receives an instantaneous horizontal "kick" in the direction of the heavy print arrow.



- Along which of the paths below will the hockey puck move after receiving the "kick"?



- The speed of the puck just after it receives the "kick"?

- Equal to the speed " v_0 " it had before it received the "kick".
- Equal to the speed " v_0 " it acquires from the "kick", and independent of the speed " v_0 ".
- Equal to the arithmetic sum of speeds " v_0 " and " v_0 ".
- Smaller than either of speeds " v_0 " or " v_0 ".
- Greater than either of speeds " v_0 " or " v_0 ", but smaller than the arithmetic sum of these two speeds.

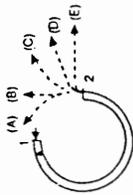
8. Along the frictionless path you have chosen, how does the speed of the puck vary after receiving the "kick"?

- (A) No change
- (B) Continuously increasing
- (C) Continuously decreasing
- (D) Increasing for a while, and decreasing thereafter.
- (E) Constant for a while, and decreasing thereafter.

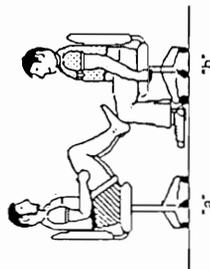
9. The main forces acting, after the "kick", on the puck along the path you have chosen are:

- (A) the downward force due to gravity and the effect of air pressure.
- (B) the downward force of gravity and the horizontal force of momentum in the direction of motion.
- (C) the downward force of gravity, the upward force exerted by the table, and a horizontal force acting on the puck in the direction of motion.
- (D) the downward force of gravity and an upward force exerted on the puck by the table.
- (E) gravity does not exert a force on the puck, it falls because of the intrinsic tendency of the object to fall to its natural place.

10. The accompanying diagram depicts a semicircular channel that has been securely attached, in a horizontal plane, to a table top. A ball enters the channel at "1" and exits at "2". Which of the path representations would most nearly correspond to the path of the ball as it exits the channel at "2" and rolls across the table top.



11. In this situation, two students, student "a", who has a mass of 95 kg and student "b", who has a mass of 77 kg sit in identical office chairs facing each other. Student "a" places his bare feet on student "b's" knees, as shown below. Student "a" then suddenly pushes outward with his feet, causing both chairs to move.



- (A) neither student exerts a force on the other.
- (B) student "a" exerts a force on "b", but "b" doesn't exert any force on "a".
- (C) each student exerts a force on the other but "b" exerts the larger force.
- (D) each student exerts a force on the other but "a" exerts the larger force.
- (E) each student exerts the same amount of force on the other.

12. A book is at rest on a table top. Which of the following force(s) is(are) acting on the book?

- 1. A downward force due to gravity.
- 2. The upward force by the table.
- 3. A net downward force due to air pressure.
- 4. A net upward force due to air pressure.

- (A) 1 only
- (B) 1 and 2
- (C) 1, 2, and 3
- (D) 1, 2, and 4
- (E) none of these, since the book is at rest there are no forces acting on it.

Refer to the following statement and diagram while answering the next two questions.

A large truck breaks down out on the road and receives a push back into town by a small compact car.



13. While the car, still pushing the truck, is speeding up to get up to cruising speed;
- (A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
 - (B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
 - (C) the amount of force of the car pushing against the truck is greater than that of the truck pushing against the car.
 - (D) the car's engine is running so it applies a force as it pushes against the truck but the truck's engine is not running so it can't push back against the car, the truck is pushed forward simply because it is in the way of the car.
 - (E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

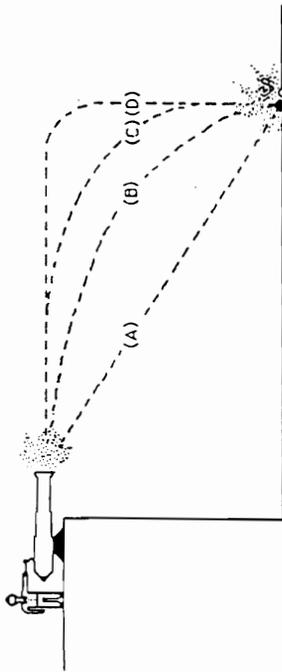
14. After the person in the car, while pushing the truck, reaches the cruising speed at which he/she wishes to continue to travel at a constant speed;

- (A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
- (B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
- (C) the amount of force of the car pushing against the truck is greater than that of the truck pushing against the car.
- (D) the car's engine is running so it applies a force as it pushes against the truck but the truck's engine is not running so it can't push back against the car, the truck is pushed forward simply because it is in the way of the car.
- (E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

15. When a rubber ball dropped from rest bounces off the floor, its direction of motion is reversed because:

(A) energy of the ball is conserved.
 (B) momentum of the ball is conserved.
 (C) the floor exerts a force on the ball that stops its fall and then drives it upward.
 (D) the floor is in the way and the ball has to keep moving.
 (E) none of the above.

16. Which of the paths in the diagram to the right best represents the path of the cannon ball?

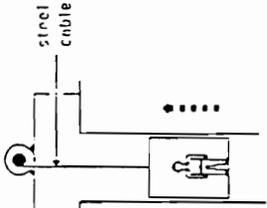


17. A stone falling from the roof of a single story building to the surface of the earth;

(A) reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
 (B) speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational attraction.
 (C) speeds up because of the constant gravitational force acting on it.
 (D) falls because of the intrinsic tendency of all objects to fall toward the earth.
 (E) falls because of a combination of the force of gravity and the air pressure pushing it downward.

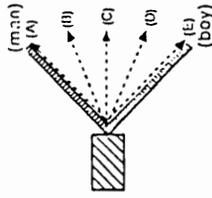
18. When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

18. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving up the shaft at a constant velocity.



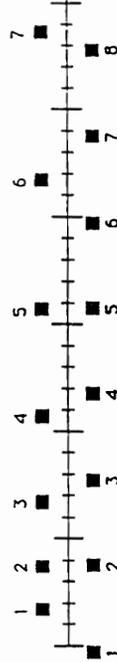
(A) the upward force on the elevator by the cable is greater than the downward force of gravity.
 (B) the amount of upward force on the elevator by the cables equal to that of the downward force of gravity.
 (C) the upward force on the elevator by the cable is less than the downward force of gravity.
 (D) it goes up because the cable is being slanted, not because of the force being exerted on the elevator by the cable.
 (E) the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.

ascending
at constant
speed



19. Two people, a large man and a boy, are pulling as hard as they can on two ropes attached to a crate as illustrated in the diagram to the right. Which of the indicated paths (A-E) would most likely correspond to the path of the crate as they pull it along?

- The positions of two blocks at successive 0.20 second time intervals are represented by the numbered squares in the diagram below. The blocks are moving toward the right.



(continued on the next page)

20. Do the blocks ever have the same speed?

- (A) No.
- (B) Yes, at instant 2.
- (C) Yes, at instant 5.
- (D) Yes, at instant 2 and 5.
- (E) Yes, at some time during interval 3 to 4.

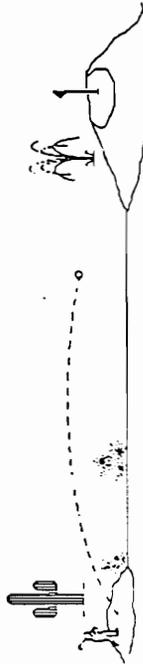
The positions of two blocks at successive equal time intervals are represented by numbered squares in the diagram below. The blocks are moving toward the right.



21. The acceleration of the blocks are related as follows:

- (A) acceleration of "a" > acceleration of "b"
- (B) acceleration of "a" = acceleration "b" > 0
- (C) acceleration of "b" > acceleration "a"
- (D) acceleration of "a" = acceleration of "b" = 0
- (E) not enough information to answer.

22. A golf ball driven down a fairway is observed to travel through the air with a trajectory (flight path) similar to that in the depiction below.



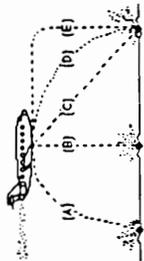
Which following force(s) is(are) acting on the golf ball during its onlre flight?

- 1. the force of gravity
- 2. the force of the "hit"
- 3. the force of air resistance

- (A) 1 only
- (B) 1 and 2
- (C) 1, 2, and 3
- (D) 1 and 3
- (E) 2 and 3

7

23. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction. As seen from the ground, which path would the bowling ball most closely follow after leaving the airplane?

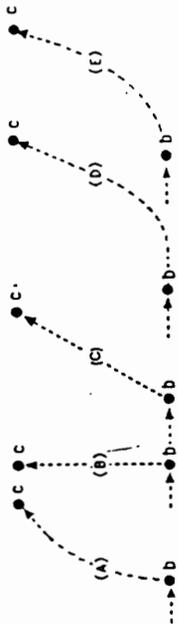


When answering the next four questions, refer to the following statement and diagram.

A rocket, drifting sideways in outer space from position "a" to position "b", is subject to no outside forces. At "b", the rocket's engine starts to produce a constant thrust at right angles to line "ab". The engine turns off again as the rocket reaches some point "c".



24. Which path below best represents the path of the rocket between "b" and "c"?

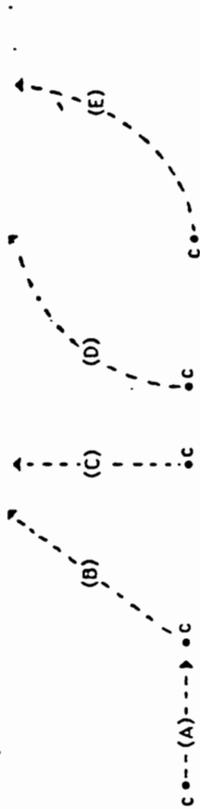


25. As the rocket moves from "b" to "c", its speed is

- (A) constant.
- (B) continuously increasing.
- (C) continuously decreasing.
- (D) increasing for a while and constant thereafter.
- (E) constant for a while and decreasing thereafter.

8

26. At "c" the rocket's engine is turned off. Which of the paths below will the rocket follow beyond "c"?



27. Beyond "c", the speed of the rocket is;

- (A) constant.
- (B) continuously increasing.
- (C) continuously decreasing.
- (D) increasing for a while and constant thereafter.
- (E) constant for a while and decreasing thereafter.

28. A large box is being pushed across the floor at a constant speed of 4.0 m/s. What can you conclude about the forces acting on the box

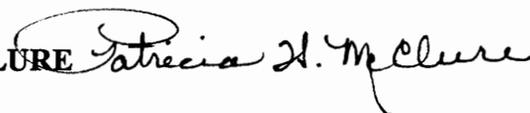
- (A) If the force applied to the box is doubled, the constant speed of the box will increase to 8.0 m/s.
- (B) The amount of force applied to move the box at a constant speed must be more than its weight.
- (C) The amount of force applied to move the box at a constant speed must be equal to the amount of the frictional forces that resist its motion.
- (D) The amount of force applied to move the box at a constant speed must be more than the amount of the frictional forces that resist its motion.
- (E) There is a force being applied to the box to make it move but the external forces such as friction are not "real" forces they just resist motion.

29. If the force being applied to the box in the preceding problem is suddenly discontinued, the box will;

- (A) stop immediately.
- (B) continue at a constant speed for a very short period of time and then slow to a stop.
- (C) immediately start slowing to a stop.
- (D) continue at a constant velocity.
- (E) increase its speed for a very short period of time, then start slowing to a stop.

VITA

PATRICIA HEAD MCCLURE



6632 Shalestone Court
Clifton, VA 22024
(703) 818-2320

EDUCATIONAL EXPERIENCE

Virginia Tech (January 1991 - present)

Major:	Curriculum and Instruction
Cognate:	Science
Advisors:	Dr. Thomas Gatewood and Dr. Thomas Teates
Dissertation:	Topic: Computer-related technology use in the high school physics classroom: A case study
Degree:	Projected: Doctor of Education in Curriculum and Instruction--November, 1996

Virginia Tech (December, 1993)

Major:	Curriculum and Instruction
Advisor:	Dr. Thomas Gatewood
Degree	Advanced Graduate Studies

University of Hawaii (September, 1970 - September, 1972)

Major:	Science Education
Degree:	Master of Education

University of Georgia (September, 1964 - June, 1966)

Major:	Chemistry
Degree:	Bachelor of Science

PROFESSIONAL EXPERIENCE

Educational Supervision

July 1993 - present

High School Science Specialist, Department of Instructional Services, Fairfax County Public Schools, VA

Responsibilities: Plan and implement all components of high school science curriculum development, technology plans, and teacher staff development; advise Office of Design and Construction on high school science facilities; coordinate with Office of Supply Services all contracts for science classroom supplies and equipment; supervise the writing of all Programs of Study for high school science standard and optional course offerings; represent FCPS high school science on committees, task forces, and panels; plan department chairperson's meetings and staff development for science teachers of the twenty-three high schools and forty-plus alternative high schools in Fairfax County; co-direct the Regional Science Fair.

July 1992 - July 1993

Director of Information Dissemination, National Science Resources Center, National Academy of Science and Smithsonian Institution

Responsibilities: Plan and provide resources for national scientists and engineers workshop; disseminate information nationally through various networks concerning exemplary elementary, middle, and high school science curriculum materials; supervise the production of revised edition of *Science for Children: Resources for Teachers* and the draft production of two works: *Elementary School Science: A Guide to Action* and *Middle School Science Resources for Teachers*.

August 1990 - July 1992

Science Program Specialist, Department of Instructional Services, Fairfax County Public Schools, VA

Responsibilities: Plan and implement all components of middle school and high school science curriculum for twenty-three middle schools, twenty-three high schools and forty alternative schools; technology planning, and teacher staff development. planned and implemented *Voyage of the MIMI* at the seventh grade and *Microcomputer-Based Laboratories* at the eighth grade level; planned and implemented a movable science technology lab at each high school.

September 1986 - August 1990

Science and Technology Special Projects Teacher, Department of Instructional Services, Fairfax County Public Schools, VA

Responsibilities: Plan and implement technology plans for the use of computer-related technologies in science classes at the elementary, middle, and high school levels in Fairfax County Public Schools; planned and implemented teacher staff development for pilot teachers in *Voyage of the MIMI*, *Microcomputer-Based Laboratories*, *KIDS Network*, and computer-use in earth science, biology, chemistry, and physics.

Teaching

August 1982 - June 1986

Classroom Teacher and Department Chairperson, Langley High School, McLean, VA

Responsibilities: Taught physics and geometry and served as Science Department Chairperson to a 14 member science department (August 1983 - June 1986).

February 1979 - June 1982

Classroom Teacher, Pace High School, Pace, FL

Responsibilities: Taught physics, chemistry, earth science, and general science. Served as Senior Class Sponsor.

August 1977 - June 1978

Classroom Teacher, Christ Episcopal Day School, Bay St. Louis, MS

Responsibilities: Taught seventh grade life science and mathematics, eighth grade physical science and mathematics, and oceanography.

August 1973 - June 1975

Classroom Teacher, Department of Defense School System, Athens, Greece

Responsibilities: Taught sixth grade science and mathematics, seventh grade science and mathematics, and eighth grade science and mathematics. Served as a science resource teacher to all grade level teachers. Implemented new curriculum, Intermediate Science Curriculum Study (ISCS).

August 1972 - February 1973

Classroom Teacher, Saint Augustine School, Honolulu, HI

Responsibilities: Taught sixth grade science, seventh grade science, and eighth grade science. Served as a science resource teacher to all grade level teachers.

Served as a pilot teacher for new curriculum, Foundation Approaches to Science Teaching (FAST).

September 1971 - December 1972

Graduate Teaching Assistant, College of Education, University of Hawaii, Honolulu, HI

Responsibilities: Assisted in methods classes for elementary teachers by maintaining science laboratory, teaching, and setting up curriculum materials including Elementary Science Study (ESS) and American Association for the Advancement of Science (AAAS).

January 1970 - June 1970

Substitute Teacher, Honolulu Public Schools, Honolulu, HI

Responsibilities: Substituted in math and science classes in grades seven through twelve.

Chemical Laboratory Supervision

January 1967 - October 1969

Analytical Chemist and Manager, Southern Analytical Laboratory, Jacksonville, FL

Responsibilities: Managed an analytical laboratory (September, 1968 - October 1969), conducted analytical chemical tests of fuel oil, water, fertilizers, and a variety of other materials.

CONFERENCE PRESENTATIONS

McClure, P., Hicks, L., & Scott, P. (1994, March). *Teaching Science Content Courses to English as a Second Language Students*. Presented at the annual meeting of the National Science Teachers Association, Los Angeles, CA.

McClure, P. & Toler, D. (1993, March). *Converting Traditional Physics to Computer-Based Physics Using an IBM Platform*. Presented at the annual meeting of the National Science Teachers Association, Kansas City, MO.

McClure, P. & Keranen, K. (1993, March). *Imaging the 21st Century*. Presented at the annual meeting of the National Science Teachers Association, Kansas City, MO.

McClure, P., Phelps, B., & Waxman, G. (1991, March). *Microcomputer-Based Laboratories Workshop*. Presented workshop at the Regional meeting of the National Science Teachers Association, Washington, DC.

McClure, P., Toler, D., and Berenty, F. (1990). *Computer Interfaced Air Track Experiments in Physics*. Presented at the Virginia Science Teachers Association, Fairfax, VA.

McClure, P. and Hamilton, J. (1990). *How Can New Technologies Be Used to Promote Restructuring?* Presented as a panel member at the Educational Commission of the States ESC/NGA Restructuring Workshop, Baltimore, MD.

McClure, P., Berenty, F., Hatch, P. and Weimer, W. (1988, March). *Computers in Earth Science, Biology, Chemistry, and Physics*. Presented at the annual meeting of the National Science Teachers Association, Washington, DC.

PUBLICATIONS

I am responsible for writing, supervising teachers' writing, and editing the following Fairfax County curriculum documents.

Chemistry Program of Studies--Draft Edition, 1996

Physics Program of Studies--Draft Edition, 1996

Adaptive Strategies for English as a Second Language Students in Biology--Draft Edition, 1995

Adaptive Strategies for English as a Second Language Students in Earth Science, 1995

Human Anatomy and Physiology: An Introduction to the Medical Sciences, 1995

Oceanography Program of Studies and Teacher Handbook, 1995

Astronomy Program of Studies and Teacher Handbook--Draft Edition, 1993

Geology Program of Studies and Teacher Handbook--Draft Edition, 1993

Concepts 1 Science and Concepts 2 Science Program of Studies and Teacher Handbook--Draft Editions, 1991, 1992, 1993

Computers in Physics Teacher Handbook and Laboratory Guide--Draft Edition, 1993

PROFESSIONAL SERVICE

December 1993 - present

High School Co-chair of Fairfax County Public Schools Science Task Force, Fairfax, VA

Reviewed present Fairfax County K to 12 science curriculum, drafts of the National Science Education Standards, American Association for the Advancement of Science Project 2061 documents, and wrote recommendations for changes in the high school science curriculum. Critiqued recommendations for middle school and elementary school science programs.

September 1993 - December 1994

Science representative on the Fairfax County Public Schools Career and Technical Task Force, Fairfax, VA

Reviewed present Fairfax County vocational programs, visited Tech-Prep schools, attended Tech-Prep conventions and workshops, wrote Academic Subcommittee report, actively participated in all meetings, and advised on the science education issued.

November 1994

Consultant, Instructional Materials Evaluator, Virginia Department of Education
Evaluated materials and critiqued VQUEST criteria for selection of instructional materials to be used in the next textbook adoption process.

June 1994 - November 1994

Consultant, Instructional Materials Evaluator, National Science Resources Center, National Academy of Science and Smithsonian Institution, Washington, DC
Evaluated instructional materials for inclusion in the revised edition of *Science for Children: Resources for Teachers*.

August 1993 - present

Committee member, High School Course Review Committee
Evaluated all courses presented for addition to the standard and optional course offerings of Fairfax County Public Schools.

September 1991 - July 1992

Science representative on the Fairfax County Public Schools High School Course Review Task Force, Fairfax, VA

Reviewed present Fairfax County course selection; met with science department chairs, teachers and administrators to recommend changes in science course offerings; wrote Science Recommendations Report, actively participated in all meetings.

March 1988 -- July 1988

Physics teacher representative on the Commonwealth of Virginia Textbook Adoption Committee

Reviewed and evaluated all physics texts submitted to the committee.

AWARDS AND RECOGNITION

Phi Delta Kappa, 1991

National Science Foundation Supervisor Grantee, Indiana University of Pennsylvania, Technology in Math and Science Workshop, 1987

Woodrow Wilson Foundation Teacher Grantee, George Mason University, Physics Teachers Institute, 1987
National Science Foundation Teacher Grantee, Florida State University, Intermediate Science Curriculum Study, June, 1974
Department of Defense School System Teacher Summer School Grantee, California of Southern California, Munich, Germany, July, 1974
University of Georgia, Academic Scholarship, 1964 - 1966
Montreat-Anderson College, Academic Scholarship, 1962 - 1964
Phi Beta Kappa, 1963

PROFESSIONAL ASSOCIATIONS

American Association of Physics Teachers
American Chemical Society--Education Division
Association for Supervision and Curriculum Development
National Association for Research in Science Education
National Science Leadership Association
National Science Teachers Association
Phi Delta Kappa
Virginia Science Leadership Association

CERTIFICATIONS

Administrator: Elementary, Middle and High School
Teacher: Physics, Chemistry, General Science, and General Mathematics