This is to certify that the

dissertation entitled

THE IMPACT OF THE MICROCOMPUTER-BASED LABORATORY
IN LEARNING PHYSICS CONCEPTS
--A CASE STUDY OF THE PSL

presented by

Shezhang Wu

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Educational System Development

Major professor

Date November 1, 1995

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.

DATE DUE	DATE DUE	DATE DUE

THE IMPACT OF THE MICROCOMPUTER-BASED LABORATORY IN LEARNING PHYSICS CONCEPTS ---A CASE STUDY OF THE PSL

By

Shezhang Wu

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Educational System Development

1995

THE IMP

This re
the impact of
concepts. The
consisting of ha
experiences. T
Michigan State
school students.
teacher.

In this st
level, subjects
temperature expe
different ways to
capabilities within
The resea

The
challenging
available in

ABSTRACT

THE IMPACT OF THE MICROCOMPUTER-BASED LABORATORY IN LEARNING PHYSICS CONCEPTS ---A CASE STUDY OF THE PSL

By

Shezhang Wu

This research used the method of qualitative/ethnographic research to investigate the impact of microcomputer-based laboratory (MBM) activities in learning physics concepts. The MBL tool was the IBM Personal Science Laboratory (PSL) package, consisting of hardware and software used together to provide science learning experiences. The research sites were located in a school district in Michigan and at Michigan State University. A total of 23 subjects participated in this research, 4 high school students, 16 middle school students, 2 graduate students, and 1 elementary school teacher.

In this study, the subjects' activities were observed at three levels. At the first level, subjects performed step-by-step procedures to complete three specific temperature experiments. At the second level, subjects designed experiments in different ways to collect and analyze data. At the third level, subjects combined parts of capabilities within the PSL program to solve some general problems.

The research results indicated that:

> The PSL program enhanced subjects' abilities to discover some challenging concepts with the use of computer graphs which were not readily available in the traditional classroom lecture or experimental labs.

techn

a lab

mathe

approx

trad

operat

for som

analys

to view

levels v

PSL pr

compe

experie

depth.

subjects

I

experien

The PSL's capability of integrating science, mathematics and computer technology allowed subjects to repeat experiments as needed several times during a lab hour--thus contributing to better understanding.

Subjects who had strong subject-matter background in physics and/or mathematics, and with strong computer knowledge could explore some complex approximations using the PSL that they would not have been able to explore in a traditional physics class.

The availability of immediate feedback, and the ability to reverse operations and present data in both graphical and tabular form provided a means for some subjects to better understand the calculation process is for data analysis.

The graphs provided by the PSL generally enhanced the subjects' abilities to view the experimental results from various perspectives.

The PSL was a user friendly program. Subjects from middle to graduate levels were able to use it easily and proficiently to learn physics concepts. The PSL provided motivation for subjects at different levels of educational competency.

The PSL provided an arena for students who had advanced computer experience and subject-matter background to explore experiments in greater depth.

The PSL supported and encouraged collaborative learning for some subjects.

In general, the PSL software and hardware provide an excellent experience for learning physics concepts.

To my parents, Yin Fen Lin and Guan Wo Wu,
who introduced me to the wonder of learning.

Many frie
made sig

To Dr. R
inspira

To Dr. La
efforts

To Dr. G
helping

To Dr. Le
disserta

To Dr. Ma
Center c
support

And especia
wife and
was not a

ACKNOWLEDGMENTS

Many friends and my family have supported me. I would like to thank those who have made significant contributions to my learning environment:

To Dr. Richard McLeod, my committee Chairperson, for his professional support and inspiration throughout my years in graduate school.

To Dr. Lawrence Redd, my committee member, who has supported my academic efforts with patience and kindness.

To Dr. Glenn Berkheimer, my committee member, for his enthusiastic support in helping me achieve my goal.

To Dr. Leighton Price, my committee member, who shared his expertise in my dissertation writing.

To Dr. Marie Emery, my former supervisor in the Media Lab and Computer Access Center of College of Education for six years and committee member, for her support of both my academic and financial situations.

And especially do I acknowledge Zhongyi Huang, Yanwen Wu and Chaowen Wu--my wife and two children for the hardships they undertook to do tasks at home that I was not able to accomplish because of the time needed for research and writing.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

and mo

software

revealed

T

The

students fo

learning phy

This

in order to ar

learning of th

The

an opportuni

without this k

measurements

accomplish m

and acceleratio

graph. The ax

CHAPTER I

INTRODUCTION TO THE STUDY

Since the development of the motion detector in the 1980s (Taylor, 1990), more and more versions of the Microcomputer-Based Laboratory (MBL) hardware and software have become available. However, an exhaustive search of the literature has revealed only three studies on the impact of MBL's on student learning.

The problem that led to this study is identified below.

Statement of the Problem

The research problem of this study is to determine whether using a MBL shifts students' focus to new learning strategies, and if it does, to what extent does it effect learning physics concepts.

This study investigates the PSL (IBM's version of a MBL) program's capabilities in order to answer questions concerning the impact of the MBL environment on students' learning of the physics concepts.

The IBM Personal Science Laboratory (PSL) is one version of a MBL. It provides an opportunity for students to gather data more quickly and more easily than they could without this kind of device. For example, the motion sensor can take distance measurements 40 times per second---far more frequently then one could ever accomplish manually. Furthermore, the software has the capability to calculate velocity and acceleration based on the changes of distance over time and displays these data on a graph. The axes of a graph can be determined by a student. In addition, the software perm

logar

learn

in vari

of the p

and in c

This d

could be add

that more stud

making phys

physics. Thus

would be able

In their

Microcomputer

permits manipulation of the data in a variety of ways including adding constants, taking logarithms, integrating, etc. Thus the MBL has the potential of shifting the emphasis in learning physics concepts from laboriously gathering and plotting data to analyzing data in various ways and making it easier to understand the implications of the data.

The rationale for this problem was drawn from the dire need to improve learning of the physics concepts.

Dissatisfaction with student desire to learn physics concepts both in high schools and in colleges has been voiced by Bork (1990) and others. Bork states:

> At the beginning of this century most graduates of secondary school in the United States had physics as one of their courses. Currently only a small fraction of secondary school students take physics. The number of students taking physics in secondary school has declined all through this century. There was some slight changes in this pattern during the development of the new curriculum, about 1960, but this was temporary. Many now think that physics should be taken in secondary school only by the few students who absolutely need it for the future. Counselors actively urge students not to take physics unless these students are exceptional or are pursuing careers for which physics would be essential."...(p32) "The situation has deteriorated to the point that a recent survey done by the National Science Teacher's Association shows that only about half the high schools in the United States currently offer a physics course. Far fewer high schools offer advanced-placement physics courses, and these high schools usually cater to the children of the wealthy. The data also show that about half of the teachers currently teaching physics are not certified to teach physics. As with physics enrollment, these figures have been moving in the same monotonic direction for long periods of time. The situation is a disaster. (p. 33)

This dissatisfaction with high school students' desire to learn physics concepts could be addressed by making teaching and learning physics easier and more attractive so that more students would be encouraged to take physics and succeed in learning it. Also, making physics more attractive might result in more teachers becoming certified in physics. Thus, more schools would have certified physics teachers, and more schools would be able to offer physics and include advanced-placement physics.

In their article, "Teaching Scientific Reasoning Skills: A Case Study of a Microcomputer-Based Curriculum," Friedler, Nachmias, and Songer (1990) addressed a major c

educat on

Bo

solve some

problems in

He c

High c

is of high qua

To imp

in computer us

a major concern of science education and enumerated new ways in which science education could be improved.

> One major concern of science education is preparing students to live in a rapidly changing society. In order to recognize, address, and shape new scientific and technological changes, students need not only understanding of scientific facts from the natural and physical science, but also problem solving skills. These expert thinking skills do not develop spontaneously. Science educators must look for ways to encourage and develop such important inquiry skills in their students. (p. 58)

Bork (1990) suggested the computer as one of the major tools to be used to solve some of the problems in physics education. He also pointed out that there were problems in the way we have utilized computers.

> We have serious problems in the learning of physics that we are now currently facing. The computer could be a major tool in overcoming these problems, but the ways we have used computers so far do not address these problems nor do anything substantial to improve the learning of physics. Many current efforts, although well intended, are counterproductive. (p. 32)

He continued to describe the use of computers in physics today:

> Although there is much talk about computers and physics classes, we see little positive net effect. So far, the computer as a learning device has made little change in the way courses are being taught. Again there are exceptions, but most of our courses are still essentially lecture and textbook-based courses, with only at best minor additions from the computer. In addition, much of the computer material available in physics is not of high quality; it lacks even the professional standards that we see in the poorer textbooks. Most of the material produced so far must be considered bits and pieces, small individual programs. It makes little difference in the extensive process of teaching physics. (p. 33)

High quality learning materials for learning physics are lacking. Since the MBL is of high quality for learning physics, it could fill this void.

To improve the way computers are used in physics, Bork suggested that the effort in computer usage in learning physics concepts should be experimental.

were d

of Scien

articles

Items tw

Rotr

mathematics

Solow

> What has happened so far should be viewed not as serious production of curriculum material, but rather as an experimental effort, we are trying out different tactics involving the computer to get some idea of the range of what is possible. (pp. 33-34)

The ways technology could be used to improve learning science and mathematics were discussed in the 1989 documents of the American Association for the Advancement of Science (AAAS) and the National Council of Teachers of Mathematics (NCTM). These articles indicated that the following topics should receive special attention. (Notice that Items two and three involve using computer technology.) The topics are:

> 1) The use of real-world problems to motivate and apply theory.
> 2) The use of computer utilities to develop conceptual understanding.
> 3) Computer-based methods such as successive approximations and graphing utilities.
> 4) The use of scientific calculators.
> 5) The connections among a program situation, its model as a function in symbolic form, and the graph of that function.
> 6) Functions that are constructed as models of real-world problems. (Roth, 1992 p. 307)

Roth recommended that new learning environments, which integrate science, mathematics, and technology were needed for physics education.

> There is one subject that is ideally suited to achieve such an integration of mathematics, technology, and science while dealing with real-world problems---physics. This fit comes from the fact that physics is rich in mappings of the real world into mathematical symbols and from here back into the real world.
>
> In order to achieve such mappings between real and symbolic worlds, and in order to achieve an integration of science, mathematics, and technology, new learning environments have to be explored. (p. 307)

Soloway (1994) pointed out that the MBL is one of these potential environments:

> Microcomputer-based labs (MBL) are an emerging technology that provide learners with new ways of seeing--and thinking about--scientific phenomena. In MBL, student connect up all sorts of probes--temperature, pH, motion--to a personal computer through a d/a converter. The data from a probe is pumped straight into a spreadsheet and graphically displayed on screen in real-time. (p. 15)

mathe

studen

multiple

T

different

student's

study. M

Chapter tw

quantitative

learning p

Learning Ph

In h

laboratories

had in learnin

In a su

The MBL appears to be an environment which achieves an integration of science, mathematics, and computer technology. In order to investigate the impact of the MBL on student's learning of physics concepts, this study considered the following specific multiple perspectives.

Rational of the Multiple Perspectives for This Study

The MBL is a learning environment that needs to be examined from a number of different viewpoints. This section examines how experts viewed related problems in student's learning physics concepts, and how scientists link these perspectives to this study. More literature review to support these multiple perspectives is given in Chapter two. Multiple perspectives were used to look at different viewpoints and quantitative viewpoints. This approach lends itself to finding a variety of indicators for learning physics.

Learning Physics Concepts Beyond the Classroom Context

In his article, "Tools for scientific thinking---microcomputer-base laboratories for physics teaching," Thornton (1987) addressed some problems students had in learning physics concepts:

> Traditional science instruction in the U.S. refined by decades of work, has been shown to be ineffective in altering student misconceptions and simplistic understandings. Even at the university level, students--science majors and not--who take postsecondary physics courses, continue to hold fundamental misunderstandings of the world about them: any science learning remains within the classroom context and has no effect on their thinking about the larger physical world. The ineffectiveness of these traditional courses is independent of the apparent skill of the teacher and student performance in such courses does not depend on whether students have taken physics courses in secondary school. (p. 230)

In a survey of physics texts, Wilson and Aubrecht (1990) found that:

Ac

content of

concepts.

physics co

learned in t

effect on th

student coul

couldn't solv

ineffective in

In ter

and select pr

concluded tha

Accord

time-scales tha

convenient. Tr

> Ninety-five percent of the content of all texts was universal and that 95 percent of the content was pre-1935. The current texts are enormous, with over 1000 problems; yet those problems emphasize only a very limited class of skills. Over 90 percent relate to analytical skills, only a small number relate to the very important estimation skills, and almost none expect students to use numerical approaches. Indeed, it is likely that a student could study physics for eight years without ever seeing a problem the teacher couldn't solve. We must engage students in the intellectual process of modern physics much earlier in their training. The microcomputer can help achieve this by permitting students to approach a wider variety of phenomena and problems than is possible with only analytic tools. (p. 46)

According to Thornton, Wilson and Aubrecht (1987), the traditional methods and content of all texts were working ineffectively in helping students' learn physics' concepts. They enumerated two problems that students encountered when learning physics concepts in the traditional way. First, the physics concepts that students learned in the traditional classroom remained within the classroom context and had no effect on their thinking about the larger physical world. Second, it was likely that a student could study physics for eight years without ever seeing a problem the teacher couldn't solve. The traditional curriculum methods of physics instruction was ineffective in solving these two problems.

In terms of helping MBL students find phenomena beyond the classroom context and select problems the teacher couldn't solve, Thornton (1987), discussing the MBL, concluded that,

> Such instruments not only extend the kinds of phenomena that can be investigated, they also measure phenomena over time-scales that are both shorter and longer than can ordinarily be conveniently used. Temperature variations can be measured over days to study diurnal temperature cycles and whether changes, while sound pressure waves are easily measured and displayed over milliseconds. (p. 235)

According to Thornton, the MBL has the capability to measure phenomena over time-scales that could be shortened or lengthened to an extent not ordinarily possible or convenient. This capability would help students to discover phenomena that were not available m

do student

Develop

Se

article, "IB

Acc

(i.e. experi

physics con

With

sophisticate

seems the

skills that

Tho

Th

skills for

Approxim

Ap

they tend

available in the traditional classroom context. Given these capabilities, to what extent do students learn physics concepts? This is the first foci of this study.

Developing Scientific Research Skills

Seiger (1990) addressed the need to develop science research skills in his article, "IBM's PSL Promotes Hands-On Learning."

> Science is about experimenting, hypothesizing and analyzing. As any science teacher will tell you, these are not easy skills to teach or learn, and often the kinds of experiments that can take place in a class-room are limited by the available equipment. (p. 2)

According to Seiger, students could not easily obtain the needed research skills (i.e. experimenting, hypothesizing and analyzing) in the traditional approach to learning physics concepts.

With the PSL, one 384K MS-DOS computer can enable students to perform sophisticated experiments much faster than is possible using traditional methods. It seems the PSL has the potential capability to assist students in obtaining the necessary skills that Seiger suggested.

Thornton (1987), discussing the potential of the MBL, predicted that,

> With such tools, students in a beginning science course can form and verify hypotheses by using the immediate world around them as a laboratory and by working in a setting in which they can understand and manipulate data, derived from the physical world, in a personal way. (p. 238)

The second foci of this study is: can the PSL help students develop the needed skills for future research?

Approximation Skills Needed for Students

Approximation skills are important for understanding physics. Unfortunately, they tend to be ignored until advanced studies. Redish (1990) points out:

Re

opportun

Wilso

explained ap

> In most versions of the current curriculum, approximation and numerical skills are left for graduate study, giving most students a distorted view of physics as an "exact" science, rather than a science where we know the range of applicability of our equations. This is particularly unfortunate, since the approach to a complex, open-ended problem (especially one where the answer is not known beforehand) is the fundamental skill of the professional scientist. (p. 17)

Redish also proposed that every physics student should have an opportunity to develop the following six kinds of skills:

> 1. Number awareness. This is the sine qua non of a physics major. Students must understand that the universe is quantifiable.
>
> 2. Analytic skills. Students must understand the concept of equations and be able to manipulate them in reasonably complex situations. This includes solving problems with up to a dozen variables, understanding the use of limiting cases, and formulating strategy and tactics for approaching a complex problem.
>
> 3. Understanding of natural scales and estimation skills. Students should understand what parameters are responsible for governing the natural scales of a problem and should be able to estimate plausible answers and the size of effects to one significant figure.
>
> 4. Approximation skills. Students should understand when an approximate equation is valid and to what accuracy. They should have some idea of ways to improve approximations by variety of techniques.
>
> 5. Numerical skills. Students should know how to solve a variety of problems that are not solvable analytically. Perhaps the two most important aspects of this skill are knowing what one can get out of a numerical calculation, and knowing when to do a numerical calculation and when to do an analytic one.
>
> 6. Intuition and large-problem skills. This includes a variety of metaskills. By intuition we mean having an understanding of when an answer looks plausible and what to check for. By large-problem-solving skills we mean such things as chunking (breaking the problem into parts), mixing library skills with analytic and numerical ones, etc. (p. 16)

Wilson (1990) also proposed six skills which are similar to Redish's and which explained approximation skills as follows:

Ac

for a profe

of physics

laborious v

learn appr

The

easily and

could provi

their educa

skills stude

Calculation s

Lea

Wilson (199

Wilso

student's ma

> Approximation skills. The student should understand when an equation is being treated approximately and the range of validity of all equations used. (p. 46)

According to Redish and Wilson, approximation is one of the fundamental skills for a professional scientist. It could be one of the ways to alter students' distorted views of physics as an "exact" science. Unfortunately, this skill involves a great deal of laborious work to collect data and do complex calculations. Traditionally, students do not learn approximation skills until graduate study.

The MBL seems to have the capability to help students collect experimental data easily and accurately and make calculations faster and correctly. Therefore, the MBL could provide the needed capability for students to learn approximation skills earlier in their education. The third foci of this study is examination of the specific approximation skills students gain from the MBL.

Calculation Skills Needed in Learning Physics Concepts

Learning physics concepts is closely related to applying mathematical skills. Wilson (1990) addressed this relationship as follows:

> Selection of topics and indeed the physics sequence itself are largely determined by the expected mathematical level of the student. (p, 46)

Wilson used the simple pendulum problem as an example to illustrate how student's mathematical background affected their learning physics concepts.

> Consider the case of the simple pendulum. The usual classroom approach is to write down Newton's second law for a pendulum, make the approximation of small angles, and then solve the resulting differential equation for the simple harmonic oscillator. But what happens at large angles? What happens when a damping force is present? Or what happens if a driving force is added? The teacher is forced to evade such questions because the students do not have necessary mathematical background to consider such complex problems. Further consideration must be delayed for several years until the students' mathematical skills develop. (pp. 49-50)

W

develope

W

addressed

The

mathematic

explained s

Wilson's example implied that student's mathematical skills needed to be developed prior to learning physics concepts. Bork (1990) stated that:

> We must realize that we cannot solve this problem for physics alone. The learning problems are too interrelated with other subject areas; many of them occur across the educational spectrum." (p. 37)..."Physics depends on other subjects such as math." (pp. 37-38)

Were students adequately prepared in mathematics in school? Stipek (1988) addressed this problem based on several studies of mathematical education.

> In Goodlad's (1984) study of over 17,000 young students, math was rated about the same as reading in a list of "liked" subjects (after art and physical education). In the National Assessment of Educational Progress, nine-year-olds ranked math as their best-liked subject; thirteen-year-olds ranked it second best, and seventeen-year-olds claimed that math was their least liked subject (Carpenter et al., 1981). Brush (1979) also shows a decline in positive attitudes toward math in the high school years. Apparently, children are not born with math anxiety. Rather, negative attitudes toward math develop over time, especially during adolescence. (p. 111)

The above studies indicated that students' enthusiasm toward learning mathematics decreased as they progressed to higher grades. The following studies explained some of the reasons:

> Lazarus (1975) suggests that the cumulative nature of math curricula (if you fail to understand on operation you are often unable to learn anything taught beyond that operation) is one explanation. (p. 111)
>
> In an observation study of math and social studies classes, Stodolsky (1985) found that math instruction had characteristics that would lead students to perceive their role in learning mathematics as primarily passive, and to believe that math is something that is learned from an authority, not figured out on one's own. She found that math classes were characterized by (1) a reliance on a recitation and seatwork pattern of instruction, (2) a reliance on teacher presentation of new concepts or procedures, (3) textbook-centered instruction, (4) textbooks that lacked developmental or instructional material for concept development, (5) lack of manipulatives, and (6) lack of social support or small-group work. The nature of instruction, the behavior expected from students, and the materials were also more similar from day to day in math than in social studies classes. This lack of variety may contribute to anxiety because students who do not do well in the instructional format used in math are not given opportunities to succeed on alternative formats. (Stipek, 1988 p. 111)

inadequa

processe

passive

H

simply ch

mathema

backgrou

understan

calculatio

foci of th

Computer

Sh

In their ar

Acc

understand

This new wa

concepts. H

traditional le

PSL progra

Thor

graphing ca

These studies indicate that students' mathematical backgrounds were very inadequate. Negative attitudes toward math have developed through poor educational processes and led students to perceive their role in learning mathematics as primarily passive.

However, the MBL environment assists students to perform calculations by simply choosing the calculation command on a computer without actually performing the mathematical procedure. This innovation could help students whose mathematical backgrounds were inadequate. However, this stimulates a new question: Do students understand the calculation process that takes place when the PSL does all of the calculations? The impact of the calculation tools within the PSL program is the fourth foci of this study.

Computer Graphs--A New Way of Seeing Science

Sneider and Barber (1990) suggested a way to use computers in teaching science. In their article "The New Probeware: Science Labs in a Box," they state:

> The best computer tools for science teaching allow students to use computers the way scientists do--to collect and analyze data in real time as an experiment progresses. In this way, students can feel the heat of a chemical reaction as they watch it being graphed on a computer, 'see' the sound of a whistle; or watch the distance, velocity, and acceleration of a cart being graphed when they roll it down a ramp. (p. 32)

According to Sneider and Barber, the MBL provides a new way for students to understand physics phenomena that they were not able to learn in the traditional lab. This new way of seeing is by using computer graphs to help students perceive science concepts. Heat, velocity and acceleration are abstract concepts taught to students in traditional lectures or labs, and many students did not understand these. However, the PSL program has the capability to display these abstract concepts in graphic form.

Thornton's research on teaching kinematics by using the MBL suggests that this graphing capability continues to increased understanding:

He inte

laborato

to repro

detector

Th

test score

researche

learning o

students a

other topic

subject-ma

study.

Attitude an

In h

described h

> . . . the lower post-test error rates for students who completed the two MBL laboratories show significantly improved kinematics understanding. (p. 864)

McDermott (1990) also conducted a study on teaching kinematics with the MBL. He interviewed 24 students who had experimented with balls and tracks in the laboratory. They were asked first to describe how they would have to move their bodies to reproduce the graphs and then to replicate them by moving in front of an MBL motion detector. He concluded that:

> Although eventually almost all the students were able to produce a correct set of four graphs, observation of their attempts revealed three general types of difficulties. One fourth of the students initially ignored their predictions and attempted to produce the desired graph by trial and error, almost as if they were playing a video game. Sometimes students appeared not to notice that the graphs they generated did not correspond in detail to the given graphs. The steepness of a line or shallowness of a curve were either not considered important or the changes needed to make the graphs match more closely could not be envisioned. (p. 274)

Thornton's research emphasized the results of the final product (i.e., the post-test score). McDermott's research emphasized students' approach procedures. Both researchers found that the visual computer graphs had a positive effect on student learning of physics concepts. However, their research was limited to college physics students and to the topic of kinematics. If the MBL were applied to other grade levels or other topics, to what extent would computer graphs help students understand the subject-matter knowledge of physics and mathematics? This is the fifth foci of this study.

<u>Attitude and Learning</u>

In his book, <u>Motivation of Teaching: A Practical Guide,</u> Wlodkowski (1978) described how students' attitude affected learning.

> Attitudes are powerful. They have pushbutton efficiency with long-term effects on human behavior. Technically they are the combination of a perception with a judgment that often results in an emotion that influences behavior. (p. 36)

"I can t

"If I eve

"Socia

"I love

"Math r

"This s

These a

an attitu

filled w

students

set beha

perseve

When s

the two-

Some literature s

attitude. In the traditio

friendly; they even fru

A powerf

pedagogi

such a too

collected

the scienc

instrumen

complicate

decreases

determine

experience

at a time

According to Tho

learning motivation and a

McDermott (1990

on students' learning att

For some

comfortab

hall. Thes

guarantee

research t

student w

The MBL is a com

students' learning attitude

> "I can't stand English."
> "If I ever have to do another math problem, I'll die."
> "Social studies is the living death."
> "I love to write."
> "Math really turns me on."
> "This social studies is fun."
> These are common expressions heard in all schools. All of them reflect an attitude. When students like what they're learning , the classroom is filled with the two-ism of motivation--optimism and enthusiasm. The students are hopeful, cheerful and confident. We are in gear. The mental set behind the students' perception is to accept, to be involved, and to persevere.
>
> When students dislike what they're learning, the classroom is filled with the two-ism of apathy--pessimism and cynicism. (p. 4)

Some literature suggested that technology has some positive impact on a person's attitude. In the traditional laboratory, some physics instruments were not user-friendly; they even frustrated students. Thornton (1987) addressed this problem:

> A powerful instrument that is difficult to use successfully offers little pedagogical advantage, especially to the novice science student. The use of such a tool by a novice often obscures the science behind the data being collected by focusing the learning on managing the tool instead of learning the science. An oscilloscope, for example, is a powerful flexible instrument when used by people familiar with its use yet is too complicated for novices. The time needed to learn to use the oscilloscope decreases their motivation to investigate and students are often unable to determine when they are making a satisfactory measurement. Such experiences contribute to a sense of failure already felt by many students at a time when they are very vulnerable. (p. 236)

According to Thornton, a non-user-friendly instrument resulted in decreasing learning motivation and affected learning outcomes.

McDermott (1990) stated that the computer environment had a positive impact on students' learning attitude:

> For some students, the computer provides an environment that is more comfortable and non threatening than the traditional classroom or lecture hall. These advantages provide reasons for optimism, but they do not guarantee improvement in the quality of instruction. There is a need for research to examine precisely what is occurring intellectually while the student works at the computer. (p. 279)

The MBL is a computer-based learning environment that could have an impact on students' learning attitudes. This is the sixth foci of this study.

Knowledge a

Conc

results in the

Neither

in computer us

reasonable to a

Results

G
ir
ir
cc
pr
m
le
pr
kn
(o
on
m

Good and

describes its effe

Ev
de
st
es
ca

Based on

assume that peop

Knowledge and Performance

Concerning the grade levels of students able to use effectively the PSL, research results in the Technical Education Research Center (TERC) indicated that:

> The students could be middle school, high school or college students. The students might be those interested in becoming physicists or those taking one of the few science courses they will have during their schooling. Surprisingly, the motion detector and associated software could be the same for this wide range of students, although the written curricular materials would be somewhat different. (Thornton, 1987, p. 230)

Neither of Thornton's articles report how students who had different backgrounds in computer usage and science education approached the MBL program differently. It is reasonable to assume, however, that background would influence how one uses the MBL.

Results showed that prior knowledge has an effect on learning.

> Gagne and Dick suggested that, 1) newly learned information is incorporated into existing schemas, 2) recall of previously learned information is influenced by these schemas, so that remembering is a constructive act, 3) schemas not only aid retention of new material by providing frameworks for storage but also alter the new information by making it 'fit' the expectations built into schemas, 4) schemas allow learners to make inference that fill in the gaps in stories or expository prose, 5) schemas are organized not only in terms of figurative verbal knowledge but also in terms of components of intellectual skills (operative knowledge), and 6) ideally, learners will became able to not only to process new information efficiently but also to evaluate and modify their own schemas. (p. 226)

Good and Brophy (1990) referred to the prior knowledge as schemas and describes its effects on the learner:

> Even when material does not lend itself to interpretation within a well-developed schema with ready-made slots, prior-knowledge effects will still occur to the extend that learners can use existing knowledge to establish a context or construct a schema into with the new information can be assimilated. (p. 227)

Based on the theory of schemas effect and prior knowledge effect, it is natural to assume that people from various educational backgrounds might approach the PSL differently.

PSL experi

to determine

knowledge in

backgrounds

Collaborative

Based

simulation pro

v
c
r
q
w
le

Roschelle

who are attemptin

collaborative lear

In "Worksh

suggested peer le

Pe
thir
list
pe
env
stu

Based on

collaborative lear

differently. If this is true, then instructors should provide various kinds of help for PSL experiments, based on the students' backgrounds. The seventh foci of this study was to determine whether students who have both computer skills and subject-matter knowledge interact with the PSL differently from those who do not have these backgrounds.

Collaborative Learning

Based on the observation of how two girls learned physics from a computer simulation program, Roschelle (1992) concluded that:

> The domain of collaboration is diverse and each perspective can offer valuable insights and tools for analysis. As research about learning as cognitive and social progresses, it is imperative that differing accounts of relationships among conceptual change and collaboration are actively questioned, elaborated, and investigated. The quest for convergence in what we mean by 'learning by collaborating' is an essential goal for learning sciences. (p. 48)

Roschelle's findings raised a question about collaborative learning for students who are attempting to learn physics concepts on a computer. His findings indicated that collaborative learning improved students' learning physics concepts in various ways .

In "Workshop Physics: Replacing Lectures with Real Experience," Laws (1990) suggested peer learning for students who are learning physics concepts.

> Peers are often more helpful than instructors in facilitating original thinking and problem solving. The time now spent by students passively listening to lectures is better spent in direct inquiry and discussion with peers. The role of the instructor is to help create the learning environment, lead discussions, and engage in Socratic dialogue with students. (p. 24)

Based on the previous research, Slavin (1985) identified some benefits of collaborative learning:

Jc

on socializ

Johnso

reinforcing the

p
s
th
tr
(p

Physics ex

collaborative learn

concepts. This is

Developing Teacher

When Turkl

confided to her:

We r
figur

This teacher

readiness which aff

toward using compu

> Cooperative learning programs have positive effects on a wide range of outcomes, including achievement, intergroup relations, attitudes toward mainstreamed academically handicapped students, and self-esteem. (Slavin, 1985 p. 13)

Johnson and Johnson (1984) addressed the need for collaborative learning based on socialization.

> At a time when being able to interact effectively with other people is so vital in marriages, in families, on jobs, and in committees, schools insist that students don't talk to each other, don't work together, don't pay attention to or care about the work of other students--students are encouraged not to care about students' learning in the classroom. (p. 7)

Johnson and Johnson believed that cooperative learning has a special function in reinforcing the school's general objectives.

> In our schools we can see to it that all of our students work to develop positive attitudes toward subject areas, such as math and science, so that students are motivated to study these subjects and to learn more about them. Those who have special aptitudes must be qualified to take advanced training, so they can possibly enter careers related to science and math. (p. 7)

Physics experiments often use a team approach. If the PSL supports collaborative learning, that capability could be used to assist students to learn physics concepts. This is the eighth foci of this study.

Developing Teachers' Computer Readiness

When Turkle (1984) interviewed a public school computer teacher, the teacher confided to her:

> We're sort of keeping it a secret. The teachers don't know. We haven't figured out all the codes yet, but we're working on it. (p. 99)

This teacher's response reflected teachers' computer readiness in public schools, readiness which affects their teaching in a computer environment and their attitudes toward using computers.

> A study of student teachers by Downes showed that experience with computers in the classroom and a good role model, in the form of a classroom teacher who uses computer, lead to more positive attitudes towards computers and an increased likelihood that the student teachers would use them in their own teaching. While most studies of teacher attitudes towards computers have tended to look primarily at either student teachers or Primary teachers, some have shown that computer literacy courses can improve teachers' attitudes. Madsen and Sebastiani report several studies showing that the greater proficiency teachers have with computers the more likely they are to use them and to exhibit less anxiety towards them. There is also evidence that teachers' positive attitudes can rub off on the students leading to improved performance. (Robertson, Calder, Fung, Jones & O'Shea, 1995 p. 73)

Research concerning the teachers' readiness was not the major emphasis in this study. However, research concerning an investigation as to whether the PSL improved the computer readiness for teachers, as it relates to students' learning physics concepts would be valuable.

Summary of the Research Foci

The research foci presented in the previous section are summarized as follows:

1. To what extent do subjects learn physics from the PSL program?

2. What computer skills do subjects gain for future research from the PSL?

3. What approximation skills do subjects gain from the PSL?

4. Do subjects understand the calculation process when the PSL does all of the calculation?

5. To what extent do computer graphs help subjects understand the subject-matter knowledge of physics and mathematics?

6. Do subjects' attitudes toward the use of computers change as they obtain computer experience while using the PSL?

7. Do subjects who have both computer skills and subject-matter knowledge interact with the PSL differently from those who do not have both skills and knowledge?

If the

research, the

enhance learn

2.

3.

8. Does the PSL support and/or encourage collaborative learning?

9. Does the PSL improve the computer readiness of a teacher?

Significance of This Study

If the MBL program is shown to be effective in learning physics concepts in this research, then there are four main and distinct ways in which the MBL may be used to enhance learning physics concepts.

1. This program can be used by an instructor to demonstrate a particular physics phenomenon during a lecture. For example, an instructor may use the MBL to show some physical phenomena beyond the traditional classroom context and, therefore, stimulate students' thinking about the larger physical world. (Research foci 1,5 & 9)
2. The MBL program may provide an arena for different grade levels of students to develop their professional science research skills and computer-based calculation skills. (Research foci 2 & 4)
3. The MBL provides learning opportunities for students which were traditionally only offered during graduate study of physics concepts. This category includes approximation. For example, an instructor may use the MBL environment to design a guided Mass-Spring Oscillation experiment; based on experimental data the instructor could then guide the student to combine Hooke's Law and Newton's second law and use the Fit-line equation (Least Square Criterion) to compute the *spring's constant* . This combination is not available in a conventional laboratory. In other words, the MBL opens a new arena for students to develop their creativity. This combination enables students to repeat their experiments quickly. Students may take this opportunity to formulate more hypotheses and test them again and

again. It provides more opportunities for students to experience how actual physicists use physics. Through these kind of practices, students could develop the necessary skills to become successful in physics courses. (Research foci 3 & 7)

4. The MBL may be used as an environment for collaborative learning, the understandable computer graphs and immediate feedback may work as a medium or agent to help students work collaboratively and develop more positive attitudes toward learning physics concepts. (Research foci 6 & 8)

Overview of All Chapters

• Chapter one states the problems and the research foci.

• Chapter two discusses issues related to the impact of computer technology to the physics concepts.

• Chapter three describes the methods and procedures used for this study.

• Chapter four presents data which relate to the research foci. The data are then presented, discussed, demonstrated, and linked to the research questions. Conclusions are drawn based on discussions of the data. Finally, the research findings are summarized.

• Chapter five uses the results of the findings to suggest and recommend ways to use the MBL to improve learning the physics concepts. Questions for further research are stated.

Susan

(Connecticut) F

years. She be

unique uses for

that the compute

notes that studen

the software is g

in cooperative lea

using the comput

Hooper (19

with individualized

individual needs ar

better in small gro

on their own. "I've

cooperative groups a

they learn better in

Hooper says

learning comes to the

never really know a s

CHAPTER II

REVIEW OF THE LITERATURE

Susan Ellis (1992), director of staff development for the Greenwich (Connecticut) Public Schools, has been involved with cooperative learning for over 12 years. She believes that teachers who are comfortable with cooperative learning find unique uses for whatever tool they use, including computers. She states, "The reality is that the computer is a tool, and you can teach collaboratively whatever the medium." She notes that students like the interaction and immediate response of computers. "Assuming the software is good, computers are very motivating tools. So for somebody who believes in cooperative learning, an added benefit is that students are happy engaging in tasks using the computer."

Hooper (1992) echoed this opinion. "Technology has been used for a long time with individualized instruction. It has been seen as a way to focus on and diagnose individual needs and prescribe accordingly." Hooper says that since children learn better in small groups, cooperative learning is frequently more effective than learning on their own. "I've been asking, 'Can kids learn computer-based instruction in cooperative groups as effectively as they can on their own?' In fact, we've found that they learn better in groups" (p. 18).

Hooper says that research has discovered that the greatest benefit of cooperative learning comes to those who give help to others. "In the same way that teachers say they never really know a subject until they teach it, a student who goes through the process of helping anc

Individual co

(p. 19).

It is r

and Hooper s

working by th

of each exper

than they wou

It was

collaborative le

questioning eac

much will be los

This stu

Laboratory (MB

gathering and pl

learning strategy

concepts?

A review

appropriate trends

literature was gro

computers differen

relate to students' a

computers; 2) the

concepts; this cate

real-world compute

provides a context f

program in learning

helping another student on a task must first organize the information in his/her brain. Individual computer workstations do not afford students this opportunity to help others" (p. 19).

It is necessary to encourage cooperative learning by using the MBL since, as Ellis and Hooper state, students learn more by discussing experiments with each other than working by themselves. Many ideas flow between students as they discuss the phenomena of each experiment. They learn new concepts about physics in greater depth and faster than they would have had they worked alone.

It was not clear to me when I began this research just how important collaborative learning was to a teacher. As I observed students and listened to their questioning each other, I realized that, unless teachers encourage cooperative learning, much will be lost as classes use the MBL.

This study was undertaken to investigate whether the Microcomputer-Based Laboratory (MBL) has the potential to shift students' emphasis from laboriously gathering and plotting data to analyzing data in different ways. If this kind of shift in learning strategy actually takes place, to what extent does it affect learning physics concepts?

A review of the literature provided the background for this study, identifying appropriate trends that were used to document this investigation. The review of literature was grouped into the following major categories: 1) how people interact with computers differently; this category provides a context for the research foci which relate to students' academic backgrounds and students' attitude toward the use of computers; 2) the role of computer simulation and approximation in learning physics concepts; this category provides a context for the research foci of approximation; 3) real-world computer-oriented experiments and their computation; this category provides a context for the research foci of the calculation process; 4) the role of the MBL program in learning physics concepts; this category provides a context for the research foci about a

computer re

context for t

This s

Turkle (1984

received six g

people interac

people used th

compared to th

levels interact

Through

including childre

video game ent

artificial intellige

computers), pro

found three stage

metaphysical, ma

> Firs
> com
> and
> con
> mas
> com
> gam
> comp
> want
> In ad
> the c
> this t

foci about learning physics concept, scientific research skills, and developing teacher's computer readiness; 5) the role of collaborative learning; this category provides a context for the research foci concerning collaborative learning.

How People Interact with the Computers Differently

This study investigates how people interact with the MBL's program differently. Turkle (1984), a professor in the Harvard University Graduate School of Education, received six grants extending over six years for a research project to observe how people interacted with computers differently. At that time, Turkle did not observe how people used the MBL program; however, her observation and findings could readily be compared to this study in order that others might understand how people of various age levels interact with the MBL program differently.

Through observing and interviewing all levels of the "computer culture," including children playing with computer toys, students using computers in classrooms, video game enthusiasts, home computer owners, virtuoso "hackers" (members of the artificial intelligence community and the first generation of people who owned home computers), professional programmers and artificial intelligence researchers, Turkle found three stages in people's relationships with computer usage. These stages were metaphysical, mastery, and identity.

> First there is a 'metaphysical' stage: when very young children meet computers they are concerned with whether the machines thinks, feels, and is alive. Older children, from age seven or eight on, are less concerned with speculating about the nature of the world than with mastering it. For many of them, the first time they stand in front of a computer they can master is when they play their first video game......these children are all involved with the question of their own competence and effectiveness. When they work with computers they don't want to philosophize, they want to win. The second stage is one of mastery. In adolescence, experience is polarized around the question of identity, and the child's relation to the computers become part of a return to reflection, this time not about the machine but about oneself. (pp. 18-19)

Turk

who succeed

Each child de

soft mastery

Watt (

w

th

Accordin

in the first stage

thought, felt or liv

stage; they were

games, they wan

stage seemed to

thought. Since a

were probably in

For people

mastery and soft m

science of the con

the soft master wo

combinations." Wa

Turkle also discovered two very different types of approaches taken by children who succeeded at the same thing, but did not accomplish the task in the same manner. Each child developed a distinctive style of mastery, styles that could be called "hard and soft mastery."

> Hard mastery is the mastery of the planner, the engineer, soft mastery is the mastery of the artist: try this, wait for a response, try something else, let the overall shape emerge from an interaction with the medium. It is more like a conversation than a monologue. ......The former (hard mastery) is a science of the abstract, the later (soft mastery) is a science of the concrete......the soft master works with a set of concrete elements. While the hard master thinks in terms of global abstractions, the soft master works on a problem by arranging these elements, working through new combination. (pp. 104-105)

Watt (1982) found that,

> . . . affluent students are thus learning to tell the computer what to do while less affluent students are learning to do what the computer tells them. (p. 59)

According to Turkle's findings, children who were under seven years of age were in the first stage of computer usage; they were concerned with whether the computers thought, felt or lived. Those who were seven or eight years of age were in the second stage; they were involved with their own competencies. When they played computer games, they wanted to win. Children who were nine or older who worked on the third stage seemed to verbalize their experiences which lent the observer to know what they thought. Since all of the subjects in the present study were over nine years of age, they were probably in Turkle's third category.

For people of the same age, Turkle found two distinctive styles of mastery: hard mastery and soft mastery. Hard mastery is a science of the abstract; soft mastery is a science of the concrete. "While the hard master thinks in terms of global abstractions, the soft master works on a problem by arranging these elements, working through new combinations." Watt (1982) also found two kinds of reactions in terms of interacting with comput

while less a

Turk

Learning.

Aronso

categories or

strategy. Gag

High-ord
Rule: D
Defined

Concrete
Discrimin

In order f
generatin
Because a
prerequisi
concepts c
be learne
Before a c
between c

From Turki

different ages and

One research foci

with computers: "affluent students are thus learning to tell the computer what to do while less affluent students are learning to do what the computer tell them."

Turkle and Watt's findings seem to coincide with Gagne's (DATE) Conditions of Learning.

> There are two kinds of learning conditions: internal and external. Internal refer to acquisition and storage or prior capabilities that the learner has acquired that are either essential to or supportive of subsequent learning. External conditions refer to various way that instructional events outside the learner function to activate and support the internal processes of learning. (Aronson & Briggs, 1995, p. 82)

Aronson and Briggs stated that Gagne classified human learning into four categories or domains: Intellectual skill, motor skill, verbal information, and cognitive strategy. Gagne also identified five types of intellectual skills:

> High-order rule: Generate new rule for solving a problem.
> Rule: Demonstrate application of a rule.
> Defined concept: Classify objects, events, or states using verbal description or definitions.
> Concrete concept: Identify instances of the concept by pointing to examples.
> Discrimination: Discriminate between stimuli that differ along one or more physical dimensions. (p. 84)

> In order for a person to demonstrate the use of a higher-order rule (i.e., by generating a new rule), the person must have learned various prerequisite rules. Because a rule is a relationship between two or more concepts, those concepts are prerequisite to learning the rule of which they are a part. Similarly, defined concepts often have as referents concrete concepts (e.g., the concept "chair" can be learned as a definition or as an object that can be physically identified). Before a concept can be learned, one must be able to make discriminations between critical attributes. (p. 84)

From Turkle, Watt and Gagne's findings, one may assume that students of different ages and with different backgrounds would interact with the PSL differently. One research foci arises from this point:

Conce

stated:

Turkle

research repo

changed throug

computers.

e
p
a
S
cc
us
w
re
wc
gr
St
far
co

In order to

Ranaweera (1990

spreadsheets. Th

newly acquired sk

questions that phys

reasonable? What

In the book

concrete examples t

- Do subjects who have both computer skills and subject-matter knowledge interact with the PSL differently from those who do not have them?

Concerning the computer's impact on people's performance, Turkle (1984) stated:

> While for some children the computer enhances personal growth, for others it becomes a place to "get stuck." (p. 19)

Turkle's findings disclosed that computer use affected people's attitudes. Other research reports indicated that people's attitudes toward the use of computers could be changed through computer training and that these attitude changes affected their use of computers.

> This was carried out by Sanders and Stone who chose five state co-educational schools to participate in a intervention field test designed to promote computer use in girls. Three of these schools were experimental and two control....(p. 190) The results of the one-term field test in Sander's words: 'exceeded not only our expectations, but our hopes. The control school with no intervention, had no increase in girls' computer use during the term. The attention control school, which had received a workshop for faculty and reminders of the project every two weeks, registered a 14% increase. The experimental schools, however, with the workshop, the bi-monthly calls, and The Neuter Computer, increased girls' computer use on average of 144% over the term. (p. 190) Stockdale has shown that encouraging female students to attend 'computer familiarization' workshops resulted in positive change in attitudes to computer use. (Siann, Macleod, Glissov, and Durndel, 1990, p. 190)

In order to determine a student's attitude toward using spreadsheet simulations, Ranaweera (1990) researched a project consisting of student responses in using spreadsheets. The results were very positive, and students were quick to try out their newly acquired skills. The spreadsheet simulation allowed students to ask the "what if" questions that physics teachers always hope for, such as, "Does the shape seem reasonable? What if we change a condition? How will it look?" (p.315)

In the book "Motivation and Teaching: A Practical Guide," Wlokowski used two concrete examples to explain how attitude affected human being's behaviors.

Stipek (

learning outcom

l
t
n
la

F
w
1

Keller illu

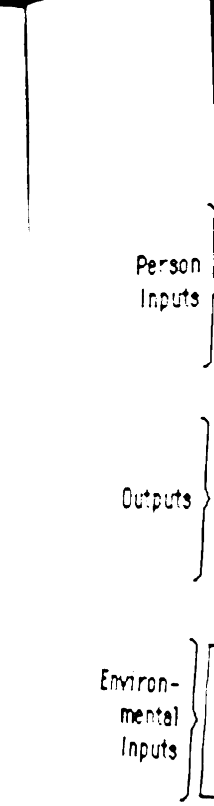
1974; Rotter, 1

> Attitudes are usually based on belief that are learned and that result from experience. A young child who enters kindergarten sees her/his teacher for the first time. The teacher is a person who reminds the child of one of her/his parents. The child loves her/his parents, and, therefore, likes the teacher and feels safe in her/his company. The child wants to please the teacher and is motivated to learn because of this. On the other hand, a 13-year-old student has heard from a friend that her/his teacher is mean and unfair. During her/his first class with the teacher, the teacher, in a matter-of-fact manner, discusses the course and its requirements. The student judges the teacher's objective style to be cold and hostile. She/he fears the teacher and wants to drop the class.
>
> Both of these examples reflect attitudes and how they influence behavior. Attitudes receive much of their power because they help students to make sense of their world and give cues as to what behavior will be most effective in dealing with what world. If someone is going to be hostile, it is in our best interest to be careful of, and even to withdraw from, that person. (pp. 36-37)

Stipek (1988) identified two kinds of attitudes that resulted in two kinds of learning outcomes:

> In Atkinson's theory, individuals who believe that they are competent at a task perceive the probability of success as higher and, consequently, are more likely to approach the task than individuals who believe that they lack competencies needed to complete the task. (p. 91)
>
> For students who lack confidence in their ability, anxiety can interfere with learning and with remembering previously learning material. (p. 103)

Keller illustrated a social-learning theory (Lewin, 1935; Hunt & Sullivan, 1974; Rotter, 1972) in Figure 2-1. (p.392)



Figur

Keller s

...behav

The illus

people's behavio

factor of persona

Keller's formula s

It seemec

supported Keller s

behavior. This su

assumption is link

• C

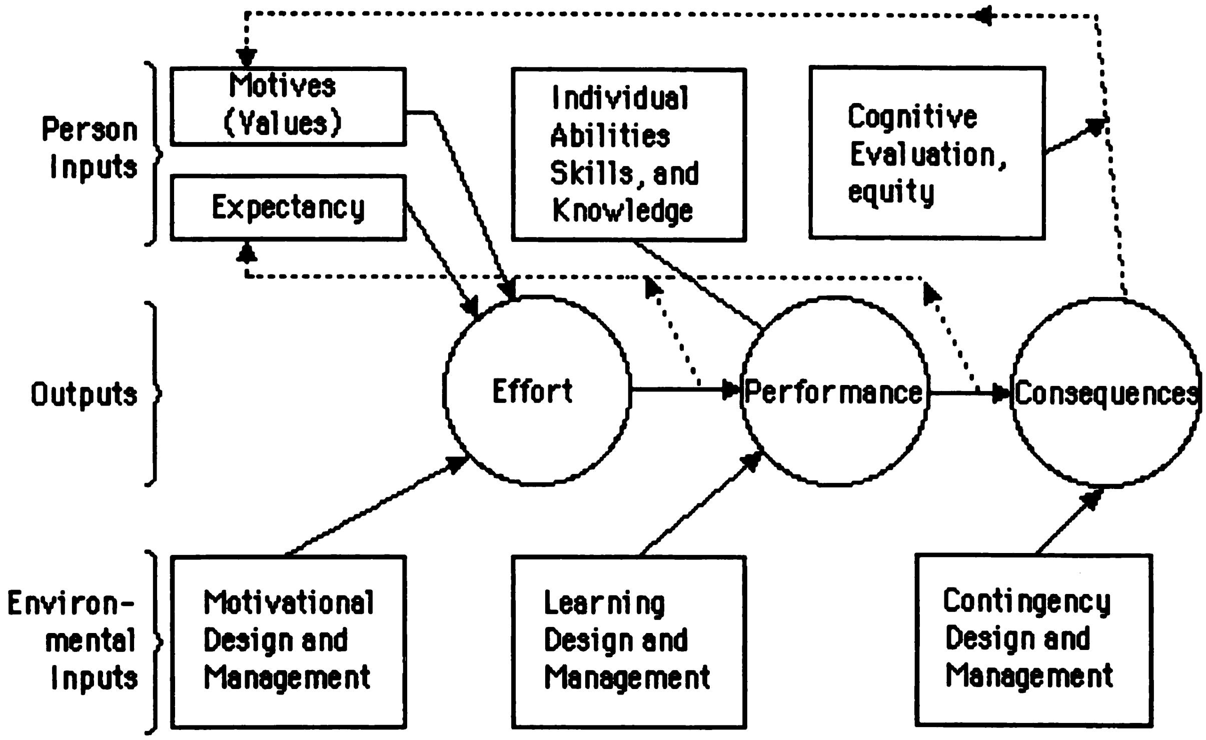


Figure 2-1 A model of motivation, performance, and instructional influence

Keller stated that:

...behavior is considered to be a function of the person and the environment:

B = f(P & E) (Keller, 1983 p. 391)

The illustration in Figure 2-1 and the formula which Keller derived stated that people's behavior was a function of two variables: personal and environmental. One factor of personal variables is "motives (values)." In other words, Figure 2-1 and Keller's formula suggested that a person's behavior is related to attitude.

It seemed that Turkle, Sanders, Stone, Stockdale and Ranaweera's findings supported Keller's theory--attitude is one of the independent variables of human behavior. This suggests that learning outcomes relate to learning attitudes. This assumption is linked to another focus in this study.

- Do subjects' attitudes towards the use of a computer change as they get computer experience while using the PSL?

The Ro...

The ...

approximatio...

The differenc...

real-time exp...

There ...

found any res...

Redish (199...

In this c...

This implied tha...

statement expla...

This author belie...

simulation and a...

calculation. In c...

related literature ...

is about compute...

approximation.

Computers ...

education for man...

incorporate scienti...

computational and ...

friendly, and the re...

The Role of Computer Simulation and Approximation in Learning Physics Concepts

The third research focus of this study is: Do subjects gain theoretical approximation skills from the Personal Science Laboratory (IBM's version of MBL). The difference between simulation and approximation is that the former does not use real-time experimental data and the latter does.

There are many reports about computer simulation, but this author has not yet found any reports about approximation. However, as mentioned earlier in Chapter one, Redish (1990) pointed out:

> In most versions of the current curriculum, approximation and numerical skills are left for graduate study, giving most students a distorted view of physics as an "exact" science, rather than a science where we know the range of applicability of our equations. This is particularly unfortunate, since the approach to a complex, open-ended problem (especially one where the answer is not known beforehand) is the fundamental skill of the professional scientist. (p. 17)

In this quote, Redish stated that approximation skills were left for graduate study. This implied that only graduate students were able to perform approximation. Redish's statement explained why research reports about approximation were so difficult to find. This author believes that research on approximation is badly needed. Computer simulation and approximation in physics have one thing in common--both deal with calculation. In order to understand the context of this research, it is helpful to look at related literature about the computer simulation. In this section, the literature review is about computer simulation and shows how it links to the research foci of approximation.

Computers have been used to provide models and simulations for physics education for many years. At present, personal computer (PC) spreadsheets which incorporate scientific functions and graphic capabilities can adequately deal with many computational and data processing needs used in physics. These are easy to learn, user friendly, and the requirement to learn a programming language is not needed. For example. W

mass suspe

to an even m

Oscillations

To pu

provided a ve

Problem." T

not be solved

constant grav

approximate a

If the

the spreadshe

The simulation

spend more ti

"Interact

following descr

describes what

When this a

just marketed a p

students were able

example, Walter (1989) successfully used spreadsheets to simulate the oscillation of a mass suspended in a viscous liquid. Guglielmino (1989) applied spreadsheet simulation to an even more complex oscillation problem which demonstrated the Amplitude of Forced Oscillations.

To pursue the question, "Why are computer simulations important," Guglielmino provided a very interesting and detailed example called "The Variable Mass Rocket Problem." This problem involved solving a second order differential equation that could not be solved exactly, except in some very special cases such as zero friction and constant gravity. However, by using a spreadsheet simulation, one could obtain an approximate answer sufficiently accurate for a solution to the physics problem.

If the simulation can be made more complicated and more realistic by changing the spreadsheet, it will be possible to include more realistic and stimulating factors. The simulation then becomes open-ended and the interested student may be motivated to spend more time learning physics (Guglielmino, 1989).

"Interactive physics" is a typical physics simulation software program. The following description from Physics Interactions (Knowledge Revolution, 1990) describes what interactive physics can do.

> Interactive physics allows users to create experiments by drawing objects on the screen. With Interactive physics, a circle drawn on the screen becomes the bob of a pendulum. A straight line connected to the bob becomes a rope. Setting this experiment in motion makes the pendulum swing back and forth on the screen.
>
> Interactive physics lets users adjust physical quantities (such as mass, friction, elasticity, and gravity) to explore their effect on an experiment. Meters measure 12 different properties including velocity, forces, energy, and momentum. Measurements can be displayed numerically, on a tachometer-like dial, or graphed with a strip chart. Vector quantities are shown with animated arrows. (p. 1)

When this author began this study, a company called "Knowledge Revolution" had just marketed a program called "interactive physics II," version 2.5. In this version, students were able to enter collected data into the program and run it on a computer to compare th

world exper

innovation i

in physics e

commonsens

scientific co

1992, p. 43

The fo

theory parado

Throug

various metap

changes in a c

sense understa

using gestures

compare the results with those generated by the simulator. Those comparisons with real world experimental data reflected a new trend of simulation toward approximation. This innovation in computer simulation is due, in part, to the fact that computer simulation in physics education creates a learning theory/paradox--physics knowledge versus commonsense understanding (i.e., students construct their own understandings of scientific concepts that is not directly compatible with scientific theory; Roschelle, 1992, p. 43).

The following examples show how computer simulation generates a new learning theory/paradox--physics knowledge versus common sense understanding.

Through observing two high school students, Roschelle found that they used various metaphors--pulling, hinging and traveling to express the fact that velocity changes in a dynamic process. Pulling, hinging, and traveling are the students' common sense understandings of vector addition. Illustrations demonstrating explanations by using gestures to relate metaphors to a situation are shown below.

Figur

The sub

Figure 2-

simultaneous ges

configuration by r

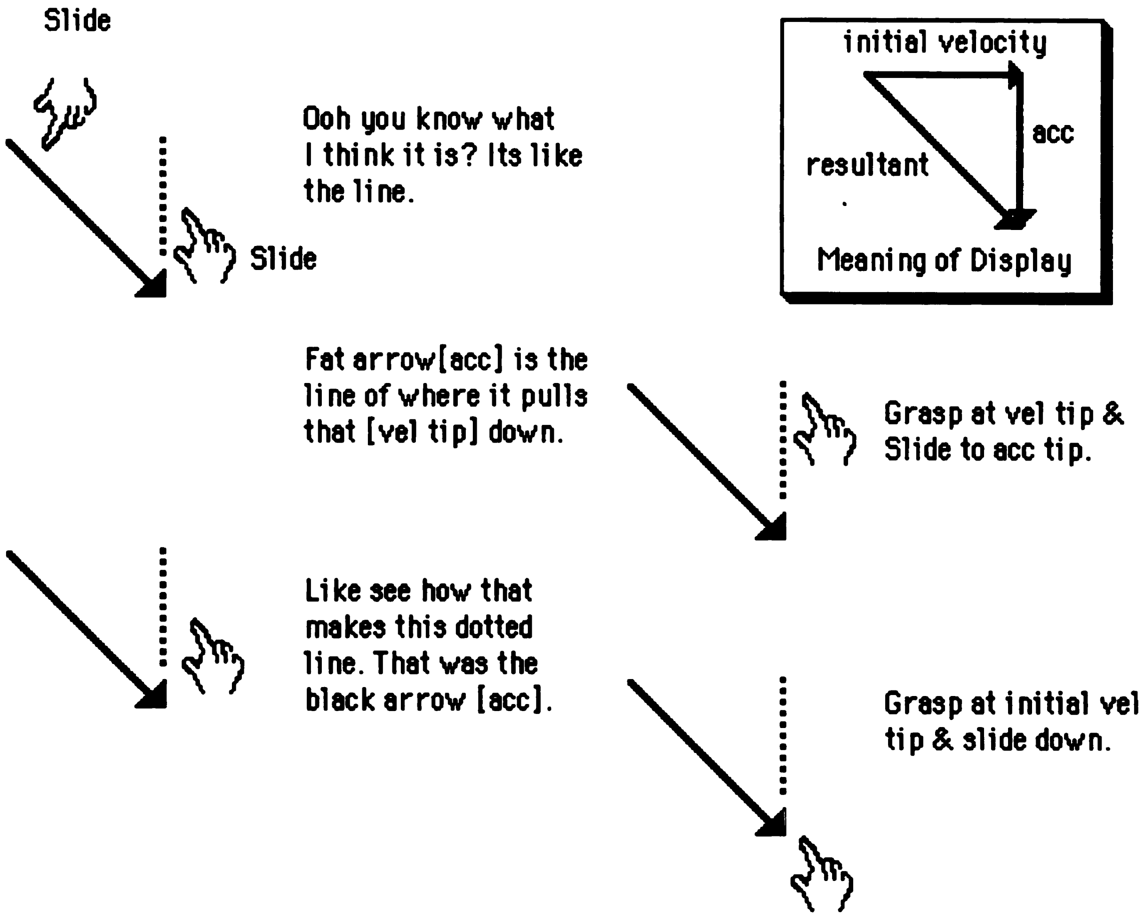


Figure 2-2 Carol described how she understood the resultant velocity by using a metaphor of pulling.

The subjects' conversation is as follows:

> D: But what I don't understand is how the lengthening, the position of the arrow . . .
>
> C: Oh, you know what I think it is ? It's like the line. Fat arrow is the line of where it <u>pulls</u> that down. Like see how that makes this dotted line. That was the black arrow. It <u>pulls</u> it. (Roschelle, 1992, p. 15)

Figure 2-2 presents illustrations of Carol's statements in relation to her simultaneous gestures to the computer screen. She developed an explanation for the configuration by reference to the metaphor of pulling.

As dis

Fig

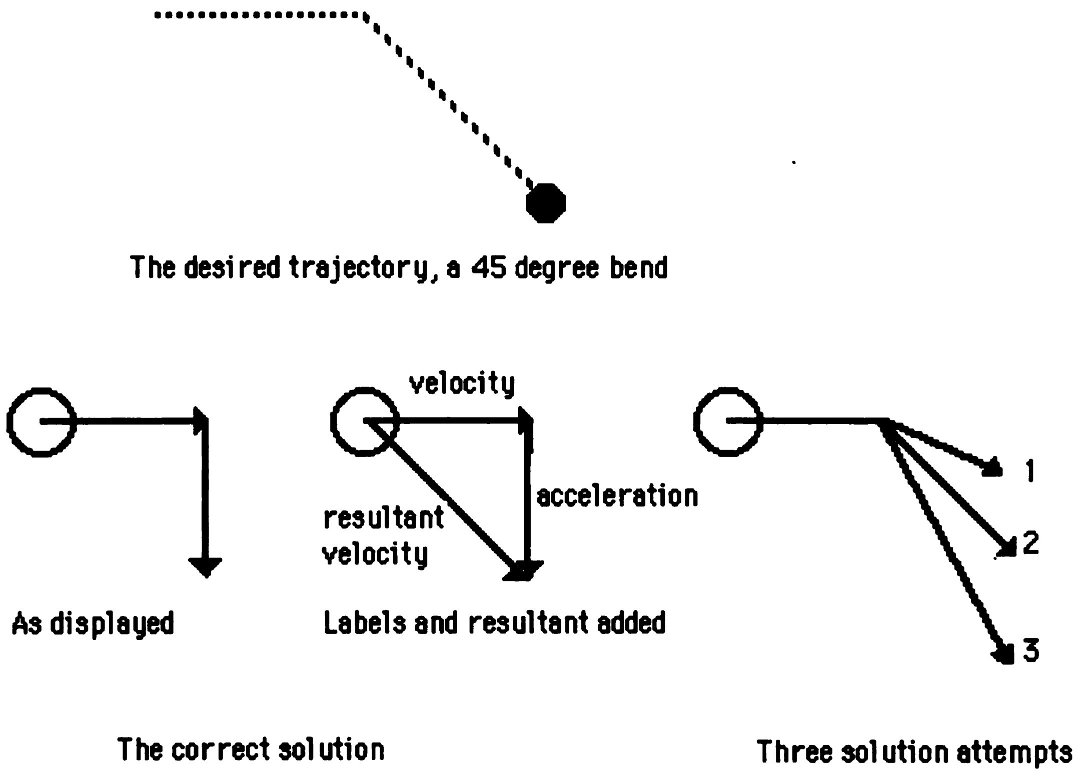


Figure 2-3 From the simulation graphs, the velocity arrows seen pivoting about its base, Carol used a metaphor of hinging to comprehend how the direction of trajectory changes.

The following are direct quotes from the subjects.

D: You are saying this [dotted line] is the black arrow?

C: Yeah.

D: And pulls it the other arrow [points to vel with mouse cursor] like
[

C: . . . like on its <u>hinge</u>. It pulls the other arrow on the <u>hinge</u> down to the tip of the black arrow.

D: Making the line that you see here [gestures to the trajectory after the 45 degree bend]

C: Right. (p. 19)

By

By "to the

is that the

the accelera

Carol st

acceleration ve

addition.

Another

that of Elastic C

simulation prog

momentum as fo

W

w

ce

ag

lik

By "on the hinge," Carol implied that the velocity arrow pivots around its base. By "to the tip of the black arrow," Carol clarified that the outcome of the pulling process is that the tip of the velocity arrow moves to the place originally indicated by the tip of the acceleration arrow.

> C: Yeah see that's right
> [
>
> D: Oh that's perfect.
>
> C: It does, it [vel] travels right along that edge [acc]. So we want it to travel that edge until there. (sets acceleration) Cause that will make it [vel] come down straight. See it [vel] will travel along that edge=
>
> D: =Yeah=
>
> C: = until it's straight down=
>
> D: =So but what we didn't realize before
>
> C: . . . might have to make it a little shorter though. (p. 31)

Carol stated that the tip of velocity "travels" along the edge formed by the acceleration vector; this was the third metaphor she used to understand the vector addition.

Another example of common sense understanding in the computer simulation is that of Elastic Collisions. Taylor (1993) observed that a student using the PuckLand simulation program, written in HyperCard, offered his own common sense definition of momentum as follows:

> Well it (momentum) is sort of just, er, the force inside them like their weight and everything going along and then it hits something and the center of gravity like pushes forward and want to go back into the center again and when it goes back it pulls the person in this case backwards, like the bounce effect with the ball. (p. 5)

Whe

studied ph,

Beca

Now the

does one deter

sense understa

simulations?"

In a stud

Taylor and his c

formal physics kr

what factors stuc

pucks after impa

cited as importan

size); and 3) wha

session (i.e., spee

friction, heaviness

when asked what w

When this student was asked to describe momentum to another student who hadn't studied physics, this student described his understanding of momentum as:

> Well I don't know the exact term but, um, it is basically one force hitting like one object hitting another object with force and bouncing off. (p. 5).

Because of the common sense understanding, Rosechelle (1992) argues that,

> Students enter science classes with a commonsense understanding of the physical world that is not directly compatible with scientific theory. Moreover, science educators and researchers widely hold the view that students must construct their own understandings of scientific concepts. Thus, student of science face the task of reconstructing their idiosyncratic common sense notions of the physical world to converge on the meaning shared by the scientific community. A large amount of research literature documents the fact that the students fail to adopt scientific meanings (e. g., Resnick, 1983; McDermott, 1984; Halhoun & Hestens, 1985 a & b; Confrey, 1990; Carramazza, McCloskey & Green, 1981; Clement, 1983; Viennot, 1979). Moreover, students' tendencies to diverge from desired meanings are exceptionally strong in science education. (p. 43)

Now the common sense understanding of physics raises another question, "How does one determine whether students use formal physics knowledge or apply common sense understandings to perceive physics concepts and calculation in computer simulations?"

In a study of challenging models of elastic collisions with a computer simulation, Taylor and his colleagues (1993) tried to determine whether students were using their formal physics knowledge or applying a common sense understanding by exploring: 1) what factors students considered to be important in predicting the motion of the ice-pucks after impact (i.e., mass, velocity, speed, weight, size); 2) what factors students cited as important when considering momentum (i.e., mass, velocity, speed, weight, size); and 3) what percentage of physics terminology students used during interview session (i.e., speed, force, energy, momentum, mass, power, velocity, acceleration, friction, heaviness, kinetic energy, potential energy, weight). The results showed that when asked what was meant by kinetic energy, half the students thought it was some sort of force w

When aske

was distan

energy and

to do with

From

are a very

provides an

Thorn

sense unders

This is

not commonly a

Thornton's

students' commor

time data require

skills are importa

of force which could be stored, while only a quarter of them associated it with movement. When asked the formula for calculating velocity, only 65% of the students knew that it was distance divided by time. Sixty-five percent could recite the formula for kinetic energy and momentum, although many of the subjects thought momentum had "something to do with" mass and velocity.

From the literature cited in this section, it is evident that computer simulations are a very useful tool in physics education. However, computer simulations in physics provides an additional effect--common sense understanding.

Thornton (1987) recommended the MBL as a tool to correct students' common sense understanding:

> MBL gives students an opportunity to investigate and correct their 'common sense' understandings of science--a necessary step on the way to building useful physical intuition--by extending the range of investigations to familiar phenomena. Students have the opportunity to verify their own intuition and modify their misconceptions. (p. 235)

This is because the MBL provides students real-time experimental data that are not commonly available to students.

> MBL instruments give students the opportunity to explore and quantify the physical world (using sensors that are not commonly available or usable by students, particularly in courses in schools and for non-majors at the university level). Such instruments not only extend the kinds of phenomena that can be investigated, they also measure phenomena over time-scales that are both shorter and longer than can ordinarily be conveniently used. Temperature variations can be measured over days to study diurnal temperature cycles and weather changes, while sound pressure waves are easily measured and displayed over milliseconds. (p. 235)

Thornton's recommendation involves dealing with real-time data to correct students' common sense understandings of science by using the MBL. Dealing with real-time data requires approximation skills. According to Redish (1990), approximation skills are important techniques for professional scientists.

App

Ba

Stude

These difficu

complex and a

of scientific p

To ren

experiments fo

because timing

data are neces

Greenslade (19

introductory phy

and experiences

way as any othe

and know how to

laboratory instrum

oscilloscope or a

instrument operat

all the details of

The basic

are the same rega

used. Three elem

> Using the computer permits us to bring in scale analysis and dimensional analysis, and to demonstrate approximation techniques and ways of extracting physics from computer programs. These are all skills that the professional must know, but that we had little opportunity to teach in undergraduate courses. (p. 20)

Approximation is one of the foci in this study.

- What approximation skills do learners gain from the MBL?

Real-World, Computer-Oriented Experiments and Their Computation

Students often have difficulty generalizing science instruction to the real world. These difficulties include 1) generalizing problems encountered in class with more complex and ambiguous problems found outside of class and 2) applying abstract models of scientific phenomena to concrete problems. (Lewis, Stern & Linn, 1993 p. 45)

To remedy this situation, physics teachers have created many real-world experiments for their students. Computers are excellent for these kinds of experiments because timing, periodic accumulation of large amounts of data, and graphical display of data are necessary for the experiments, and computers handle all very well. Collings and Greenslade (1989) began using a computer as a laboratory instrument in their introductory physics courses at Kenyon College in the fall of 1986. From their practice and experiences, they recommended that the laboratory computer be viewed in the same way as any other piece of apparatus, (i. e., students need to understand its capabilities and know how to use it, when appropriate.) After the novelty of using the computer as a laboratory instrument wears off, students should regard it in the same light as an oscilloscope or a voltmeter. They need to know the basic principles on which the instrument operates and how to make it perform properly, but they do not need to know all the details of its inner workings (pp. 76-84).

The basic considerations for performing experiments with the aid of a computer are the same regardless of the particular computer and data acquisition system being used. Three elements involved in most experiment applications are: 1) timing,

typ
ap
oc
tc-

fol
Ne
Va
Ea

ex
co
of
kn
tha
Mi
da
co

ing
mo

typically on the millisecond level; 2) measurements of voltages presented in the apparatus and conversions to a digital form (analog-to-digital conversion); and 3) output, in the form of voltage signals of digital value generated in the computer (digital-to-analog conversion).

Based upon these considerations, Collings and Greenslade (1989) designed the following computer-oriented experiments: Kinematics of Constant Acceleration, Newton's Law of Cooling, Angular Collisions, Simple and Compound Pendula, Heat of Vaporization of Liquid Nitrogen, Resistance-Capacitance Circuits, Magnetic Field of the Earth, and Diffraction and Interference Phenomena.

The major drawback was that to perform the above computer-oriented experiments, students needed to learn computer programming also. In a real-world computer-oriented experiment, a computer is viewed in the same way as any other piece of apparatus--that is, a tool. To obtain correct experiment results, students need to know the computational process in order to write a correct computational program, so that they could analyze the data they collected from the real-world experiment. In the MBL environment, students do not have to learn programming in order to analyze the data because the computer provides the various calculation commands. This new computer environment, however, raises a new question:

- Do learners understand the calculation process when the program does all of the calculation for them?

One research focus addresses this issue.

The Role of MBL in Learning Physics Concepts

By the early 1980s, TERC (the Technical Education Research Centers, Inc., an independent nonprofit development group in Cambridge, Massachusetts) developed a motion-detector. Since then, several versions of MBL have been developed. The MBL transform

and disp a

W

learning o

students a

reports a

needed

(

laborat

T

motion w

In 1

University o

project whic

college and

reported the

transformed a student laboratory experience by providing experiment inputs, analysis, and display routines.

What is the impact of the MBL? How can it be used to enhance the teaching and learning of physics? Can it be used to create a new learning environment so that students are able to learn physics concepts by doing physics on their own? Three reports about the usage of MBL were found by this researcher. More research is badly needed on this topic.

One report entitled "Tools for scientific thinking---microcomputer-based laboratories for physics teaching" by Thornton (1987) identified the following:

> A motion unit for middle school students was designed as part of the Microcomputer-Based Laboratory Project at the Technical Education Research Centers, a five-year project funded by the National Science Foundation and primarily concerned with the production, dissemination and evaluation of MBL materials (hardware, software and curriculum units) for middle school science. This project is directed by Robert Tinker, who has been a pioneer in developing the type of MBL instruments discussed here. (p. 233)

The observational notes of this research showed that students' understanding of motion was substantial and not easily changed by counter suggestion.

> The girls made a velocity graph of a cart that was speeding up. Their graph correctly showed a positive slope. As they began answering worksheet questions about the graph. Their classroom teacher came over and told them that their graph was wrong. 'No, it's not.' replied one of the girls, 'see how it gets faster, that's why the graph keeps going up.' 'It should be level.' said the teacher. 'No, it shouldn't !' insisted the girls. 'Level would mean that it's going the same speed.' The teacher shrugged his shoulders and walked off. 'We got it right.' said one of the girls, and the others nodded. (p. 234)

In 1987 and 1988, Thornton and Sokoloff (1990) conducted a study at the University of Oregon and Tufts University under The Tools for Scientific Thinking project which introduced the MBL at the college level. Their research involved 1500 college and university students in an Introductory Physics Laboratory course. They reported the results of teaching kinematics by using the MBL.

(1) *Students focus on the physical world.* Students learn concepts by investigating the physical world rather than only manipulating symbols or discussing abstractions as is common in traditional courses. However, in this learning environment, action in the physical world are directly linked to useful abstractions. For example, students who see the motion of their own bodies and of other objects displayed graphically in real time learn kinematics effectively.

(2) *Immediate feedback is available.* The immediate feedback helps to make the abstract more concrete. The immediate coupling of the graphs to the physical phenomena seems to lead the students not only to understand graphing as a useful scientific symbol system, but also aids understanding of physical concepts when students are guided to examine appropriate phenomena. These observations are consistent with previous studies on a small number of students which suggested that even a short delay in the display of data in graphical form can reduce learning.

(3) *Collaboration is encouraged.* Immediate feedback supports collaborative learning and collaborative work provides immediate feedback. Because data are presented in an understandable way, students can discuss the validity, the meaning, and the implications of the data with their peers. Learning is also enhanced by encouraging students to express their predictions and to discuss unexpected results with their peers. This process appears to be a powerful one in learning about the students' alternative representations and in making them aware of them. The process of working collaboratively is closer to the way scientist actually work.

(4) *Powerful tools reduce unnecessary drudgery.* Instead of the time-consuming drudgery usually associated with data collection and display in the physic laboratory, student time is spent observing physical phenomena and analyzing and interpreting abstract presentations of these phenomena (graphs). Students are able to concentrate more on discovering and understanding scientific concepts, and critical thinking skills are more easily developed. Hypothesis development and verification is encouraged by the ease and rapidity of repeating observations with changed experimental conditions. Powerful tools allow students to focus on authentic tasks in ways characteristic of scientists in the workplace. This is not commonly the case in school environments.

(5) *Students understand the specific and familiar before moving to the more general and abstract.* The environment guides students to understand a specific, familiar (but often more complex) phenomenon before moving to the consideration of more general and abstract examples. Most students seem better able to understand motion when first considering, for example, their own motion (as complex as it is) as a reference point and then moving on to more idealized, less familiar (and less complex) motions with more general applicability such as frictionless motion or simple harmonic oscillation. Although it is difficulty to abstract simple laws of physics from a complex, real process, grounding student

B

Th

which the s

It was also

in order to

MBL enviro

students wi

articles did

available wi

generated in

> understanding in the specific and familiar seems to make the abstract concepts more learnable. Moving from the specific to the general when investigating new concepts may also be more characteristic of the scientific workplace than the usual teaching and learning environment. (p. 866)

Based on their research, Thornton and Sokoloff also pointed out:

> The MBL tools give students the opportunity to do real science in the introductory physics course. Thus students can experience the excitement of the process of science--the creative building and testing of models to explain the world around them. These tools give the science learner unprecedented power to explore, measure, and learn from the physics world. Because of their ease of use and pedagogical effectiveness, they make an understanding of physical phenomena more accessible to the naive science learner and expand the investigations that more advanced students can understand.
>
> The tools, however, are not enough. Preliminary evidence shows that while the use of the MBL tools to do traditional physics experiments may increase the students' interest, such activities do not necessarily improve student understanding of fundamental physics concepts of the type discussed in this article. These gains in learning physics concepts appear to be produced by the combination of the tools and the appropriate curriculum materials. In general, students improve their understanding of the physical concepts when they are guided by a curriculum to examine appropriate phenomena. (Thornton & Sokoloff, 1990, p. 865)

Thornton and Sokoloff's research results indicated that the physics concepts which the students learned from the PSL were not easily changed by counter suggestions. It was also important to know that some appropriate curriculum materials were needed in order to guide them through the examining process of the physical phenomena in the MBL environment. This indicated that the MBL environment does not guarantee that students will be able to learn physics automatically. In addition, Thornton and Sokoloff's articles did not report whether students were able to learn physics concepts which were available without the MBL. Was the MBL able to do this? One research focus is generated in this context.

- To what extent do students learn physics from the MBL program?

T

Scientific

as a spe

Oregon a

W

class at .

cylinders

(chicken

following

above fo

Fr

double ra

soup.

The following report was from Xavier University, a participant in the "Tools for Scientific Thinking" project (Thornton & Sokoloff, 1990). This report could be viewed as a specific example of Thornton and Sokoloff's research findings at the University of Oregon and Tufts University.

When Toepker (1993) taught Galileo's Damped Oscillator concepts in his physics class at Xavier University, he asked his students to do experiments with the following cylinders: 1) solid aluminum, 2) semirigid core (tomato soup), 3) semiliquid core (chicken noodle soup), and 4) liquid core (can of soda pop), and then match the following graphs of displacement versus time on a symmetrical double ramp for the above four different cylinders.

Figure 2-4 shows four graphs of displacement versus time on a symmetric double ramp for four different cylinders: noodle soup, soda pop, solid aluminum, tomato soup.

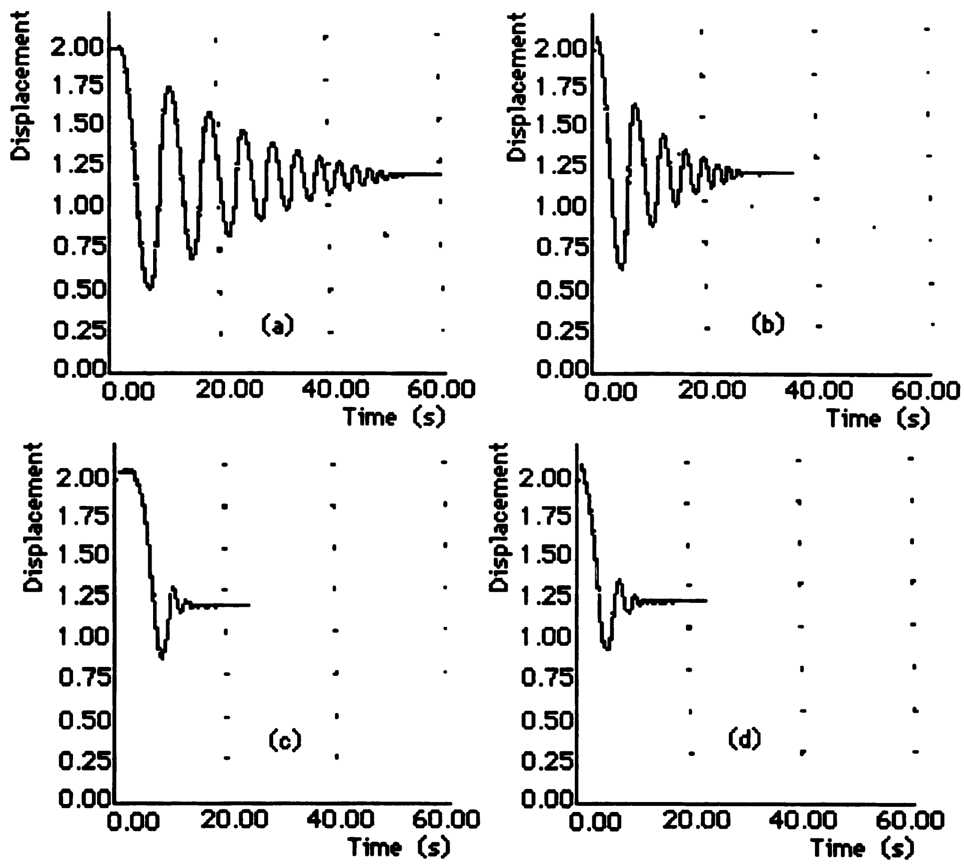


Figure 2-4 Displacement versus time on a symmetric double ramp for four different cylinders: noodle soup, soda pop, solid aluminum, tomato soup.

The question he raised with his students was:

> Can you match the correct displacement graph with the appropriate cylinder rolling back and forth on the double ramp? (Toepker, 1993, p. 538)

The answers were surprising:

> When I first started using this experiment in lab last year, I thought that every student would understand immediately. Well, how wrong I was ! (p. 537)

W

Fig

A

the displa

on the do

positive c

As

were calc

2-5 show

velocities

zero at th

because t

In

series of

What went wrong?

Figure 2-4 illustrates the experiment set up.

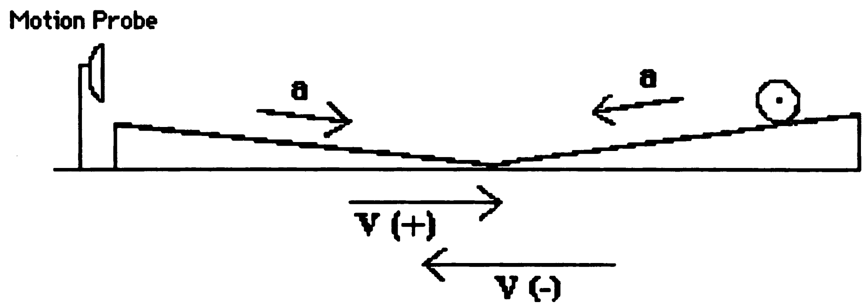


Figure 2-5 The experiment arrangement--Symmetrical double ramp

A motion probe was placed on the left side of double symmetric ramps to record the displacement of a cylinder. Once a cylinder was made to roll, it rolled back and forth on the double ramps. As a result, the displacement in this arrangement was always a positive quantity measured to the right of the detector.

As the aluminum cylinder rolled down the ramp, the velocity and acceleration were calculated from the displacement which was measured by the motion probe. Figure 2-5 shows velocity versus time for the aluminum cylinder. Note that in the schematic, velocities to the right were positive and to the left were negative, and the velocity was zero at the endpoints (highest points reached). This was often confusing to students because they knew that the displacement was maximum or minimum at the end points.

In order to help his students understand the graphs, Toepker (1993) used a series of questions/requests to direct the students' attention. See Figure 2-5.

1) Show me from a point on the graph where the cylinder was on one of the ramps at a particular time. For example, in the following Figure what point on the double ramp approximately corresponds to each of the points A through H that are marked on the graphs above the ramp?

Figu

Toepke

data collected b

students still ma

positions on the

Compare

were mentioned

2) Show, on the velocity-versus-time graph, how to get the acceleration.

3) What would the displacement and velocity graphs look like if the ramps were not symmetric? For a specific example, what would happen if the end of one ramp were twice as high as the other? (pp. 538-539)

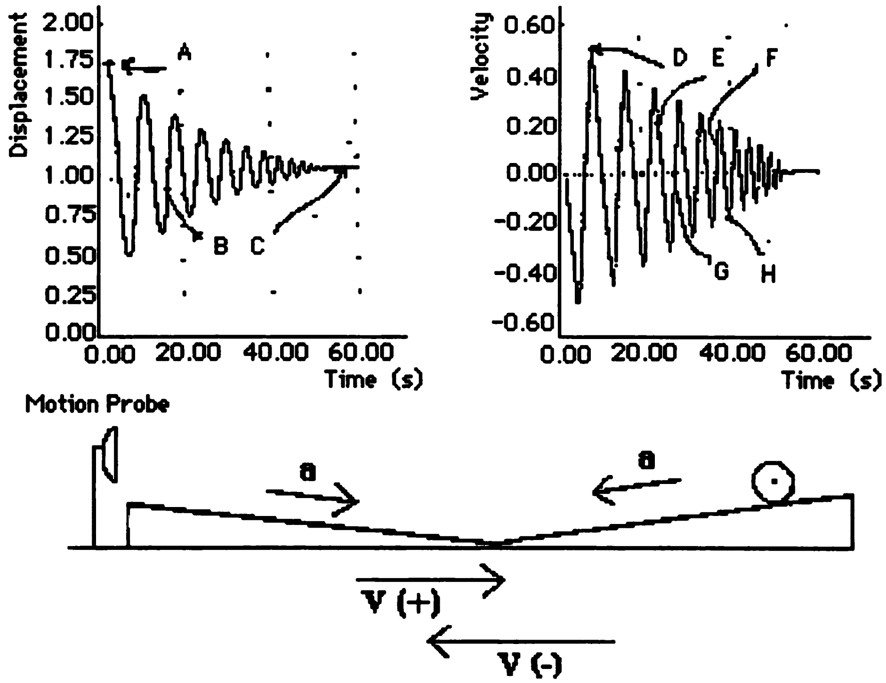


Figure 2-6 Displacement and velocity versus time for an aluminum cylinder on the double ramp. Letter A through H identify points for students to describe.

Toepker's (1993) teaching experience showed that: even though the experimental data collected by the MBL were precise and the computer display graphs were obvious, students still made mistakes in matching the displacements of the cylinders with their positions on the graphs.

Compare Toepker's (1993) findings with Thornton's (1990) findings, which were mentioned earlier in this section:

unc

ask

doin

and

the ME

was on

> The immediate coupling of the graphs to the physical phenomena seems to lead the students not only to understand graphing as a useful scientific symbol system, but also aids understanding of physical concepts when students are guided to examine appropriate phenomena. (Thornton & Sokoloff, 1990, p. 866)

Their different findings implied that computer graphs assisted students' understanding physics concepts under certain circumstances. One question should be asked:

- To what extent do computer graphs help subjects understand the subject-matter knowledge of physics and mathematics?

Thornton (1987) also predicted that:

> With such tools students in a beginning science course can form and verify hypotheses by using the immediate world around them as a laboratory and by working in a setting in which they can understand and manipulate data, derived from the physical world, in a personal way. (p. 238)

Thornton's prediction implied that MBL had potential capabilities for students doing research. With assistance from Tinker and Thornton (DATE), Friedler, Nachmias and Songer (1989) conducted a science experiment within MBL environment.

> "The Swimming Pool Investigation," confronted the students with a novel situation in which they acted as swimming pool design consultants. Students were asked to determine the effect of surface area on the cooling rate of a swimming pool's water. Prior to performing the experiments they designed, students made predictions on the cooling rate of two swimming pools with different surface areas. They drew a prediction graph and were asked to justify their predictions based on their previous experiments. (p. 63)

Although there were no details reported on this experiments, they indicate that the MBL can be used for students to practice scientific research. The following question was one of the foci of this study.

impact

This stu

teacher

might su

T

& Scanlo

presentin

In

defined co

- What computer skills do learners gain for future research from the MBL?

The observational notes at TERC (Thornton, 1987) indicated that MBL had an impact not only on students' learning, but also on the role of teachers in classrooms. This study focused on the impacts on students' learning. One question related to the teachers' readiness is also address in this study. That is:

- Does the MBL improve the computer readiness of teachers?

The Roll of Collaborative Learning

Most educators agree that collaboration enhance learning. As to how computers might support collaborative learning, O'Mlley and Scanlon (1990) stated that:

> When one considers how the computer might support collaborative (as opposed to individual) activity other roles become appropriate. One possibility is for the computer to act as a medium for joint activity (e.g. networking); another perspective is that the computer acts as a cooperative agent in the performance of tasks. A third view is that the computer is a tool for cooperative activity. These view are not mutually exclusive. (p. 129)

Thornton and Sokoloff's (1990) findings from MBL research supported O'Malley & Scanlon's assumption. Thornton and Sokoloff found that the MBL's capability of presenting data in an understandable way worked as a medium to encourage discussion.

> Because data are presented in an understandable way, students can discuss the validity, the meaning, and the implications of the data with their peers. (Thornton and Sokoloff, 1990, p. 866)

In their book, <u>Constructing Knowledge Together</u>, Wells & Chang-Wells (1992) defined collaborative talk and identified some characteristics. They stated that co

Th

focus

collaborative talk would help students to achieve specificity in achieving their goals. There were various strategies that educators might use to guide collaborative talk.

> So what is collaborative talk? Conceived quite generally, collaborative talk is talk that enables one or more of the participants to achieve a goal as effectively as possible . . . The occasions for collaborative talk may thus be very diverse. But what they all have in common is that, at some level of specificity, one of the participants has a goal that he or she wishes to achieve and the other participant engages in talk that helps the first to achieve that goal. (p. 58)
>
> Thus, whether in incidental learning situations in the home or in the more deliberate situations that teachers arrange in the classroom, the principles that should guide the adult's participation in collaborative talk are essentially the same. Adapted from Wells (1986), they can be stated as follows:
>
> - Take the child's attempt seriously and treat it as evidence of his or her best effort to solve the problem unaided.
> - Listen carefully to the child's account and request amplification and clarification as necessary to ensure that you have correctly understood.
> - In making your response, take the child's account as a starting point and extend or develop it or encourage the child to do so him- or herself.
> - Select and formulate your contribution in the light of the child's current manifested ability as well as of your pedagogical intentions, and modify it, as necessary, in the light of feedback provided by the child. (p. 59)

In order to empower learning and achieve the benefits of having two minds focusing collaboratively, Wells & Chang-Wells recommended some strategies:

> So far we have looked at collaborative talk in very general terms, considering the contexts in which it is likely to flourish and the conditions that must be met if it is to empower learning. Now we wish to examine the nature of collaborative talk more closely in order to identify those characteristics that promote the sort of reflective and systematic thinking on which such learning depends.
>
> In order to achieve the benefits of having two minds focusing collaboratively on a problem, The participants must achieve inter-subjectivity in their representation of the task in hand and of their proposal for dealing with it. Each needs to know the other's understanding

> and intentions, and both must take the appropriate steps to ensure that mutual understanding is maintained. There is a need, therefore, to be explicit. Thus, in order to explain the matter in hand sufficiently clearly for the other participant to make an informed response, each is forced to construct a more coherent and detailed verbal formulation than would be necessary if he or she were working on the problem alone. In the process, gaps and inconsistencies become apparent and can be repaired, with the result that the problem is seen with greater clarity. (p. 60)

According to Wells & Chang-Wells, participants in collaborative talk need to know each other's understandings and intentions, and both need to take appropriate steps to ensure that mutual understanding be maintained in order to achieve the benefits of having two minds focusing collaboratively on a problem.

In 1982, Yu presented an educational communication model depicting communication between teacher and student in a conference of Educational Communication and Technology at South China Normal University. He pointed out that technology could be used to enhance communication between teacher and student. For example, a video presentation may help a science teacher visualize his/her idea about how electricity works so that students understand the abstract concept of electricity. He used two circles to illustrate the communication between teacher and student.

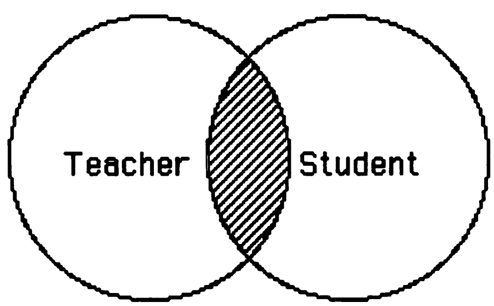


Figure 2-7 Teacher-student's communication

These two circles represent a teacher and student's knowledge and experiences. The overlapped portion represents the teacher and student's common knowledge and experiences indicating that they could share their knowledge and experiences and co

ha

co

th

as

st

to

an

we

ov

ha

in

th

en

communicate with each other. The bigger the overlapped portion that teacher and student had, the more they were able to communicate with each other. Educational technology could be applied in order to enhance their communication. It is possible that the more the teacher and the student communicate with each other, the more common knowledge and experiences they will receive. Therefore, the overlapped portion of teacher and student's common knowledge and experiences becomes enlarged (Yu, 1982). According to Yu, the communication between teacher and student relates to their prior knowledge and experiences.

Applying Yu's educational communication model to students who learn physics by working together in the PSL environment, the model could be changed as follows:

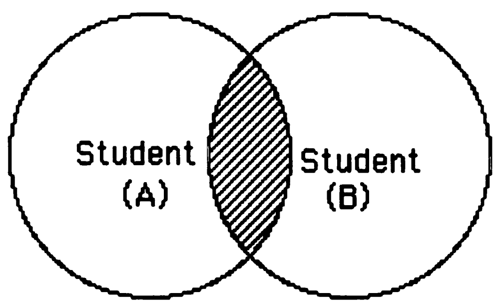


Figure 2-8 Student-student collaborative learning

These two circles represent two students' knowledge and experiences. The overlapped portion is the subjects' common knowledge and experiences.

According to Wells & Chang-Wells (1992) and Yu (1982), the benefits of having two minds focusing collaboratively relate to several factors. These factors include relational systematic thinking as well as subjects achieving intersubjectivity in their representations of a task.

In Thornton and Sokoloff's (1990) research, they concluded that collaboration is encouraged. Notice that Thornton and Sokoloff's research population was college and

t

r

t

th

p

co

Th

in

115

is f

edu

university students who took the same physics class, an introductory physics laboratory, for one year. This suggested that these students knew each other very well and that the MBL program became familiar to them. They did not report whether collaboration was encouraged when students worked together with the MBL for a short time. They also did not report whether the MBL encouraged collaboration for students who were not college or university physics students. One research focus addressed this issue.

- Does the MBL support and / or encourage collaborative learning?

Summary of the Literature Review

According to Turkle's (1984) findings, all the subjects in this study were in the third age level (9 or 10 years); their performances on the computer programs reflect their thinking. There were two distinctive styles of mastery: hard mastery and soft mastery. Applying Turkle's findings will help the reader understand how the subjects in this study used the MBL program.

Attitude affects a person's performance. Attitudes help students make sense of their world and give cues as to what behavior will be most effective in dealing with people and tasks.

The computer simulation is a very useful tool in physics education. However, the computer simulation in physics has a side effect--common sense understanding. Thornton (1987) recommended that the MBL could be used as a tool for students "to investigate and correct their 'common sense' understandings of science."

This author did not find any reports about approximation. According to Redish (1990), "approximation" was left for graduate study in most current curricula; if this is true, it explains why it was so difficult to find this kind of research for earlier education. Research concerning approximation is badly needed.

teaching

and comp

automatic

students t

difficulty in

double ram

Tho

MBL could

It is

empower le

some strate

investigate

systematic

The

physics bet

concepts w

will learn st

The

Chapter Thr

Thornton and Sokoloff's (1990) research findings and Toepker's (1993) teaching experience showed that an environment which integrates science, mathematics and computer technology does not guarantee that students will be able to learn physics automatically. Thornton and Sokoloff's findings indicated that computer graphs assisted students to understand physics concepts. However, Toepker found that students had difficulty in understanding computer graphs which were generated from a symmetric double ramp.

Thornton, Friedler, Nachmias and Songer's (1989) findings indicated that the MBL could be used for a student to practice research.

It is possible to use the MBL to encourage collaborative learning. In order to empower learning and achieve the benefits of having two minds focusing collaboratively, some strategies need to be employed. These strategies are to encourage students to investigate physics' phenomena by achieving intersubjectivity, obtaining relative and systematic thinking, as well as questioning the reasons for the outcomes.

Therefore, findings indicate that computer graphs are conducive in understanding physics better. The MBL with this capability assists students to understand physics concepts with more clarity. Through the use of graphs and collaborative effort, students will learn strategies needed to understand physics concepts.

The procedures used in this study to investigate the research foci are outlined in Chapter Three.

Th

student's fo

learning ph

procedures

organized in

versus qua

tools, 6) s

and 10) su

This

ethnograph

interactionis

Ethn

different pe

example, co

evaluators as

teacher) may

teacher is con

of the techniqu

student) may fo

CHAPTER III

DESCRIPTION OF RESEARCH METHODOLOGY

The primary purpose of this study is to determine whether using an MBL shifts a student's focus to new learning strategies; and, if it does, to what extent does it affect learning physics concepts. The qualitative method of data collection and analysis procedures employed in conducting the study is described in this chapter. The chapter is organized into 10 sections: 1) method chosen for this study, 2) qualitative method versus quantitative method, 3) validity of the qualitative method, 4) subjects, 5) tools, 6) site, 7) subjects' activities, 8) data collection, 9) methods of data analysis, and 10) summary of the chapter.

Method Chosen for This Study

This research used a qualitative method that is "alternatively called ethnographic, qualitative, participant observational, case study, symbolic interactionist, phenomenological, constructivist or interpretive" (Erickson, 1986).

Ethnography is based on the philosophy of phenomenology, which assumes that different perspectives of reality are equally valid (Bogdan & Biklen, 1982). For example, consider a situation in which a teacher is being evaluated by a group of evaluators as he/she teaches a lesson in physics. The first evaluator (e.g., another teacher) may perceive the situation in terms of the instructional content that the teacher is conveying; the second evaluator (e.g., an administrator) may see it in terms of the techniques (teaching strategies) that are being applied; the third evaluator (e.g., a student) may focus on the teacher's attitude in teaching.

perspect

this class

communi

them, and

identify th

Sin

research re

population

quantitative

(Toothaker

Becaus

method the res

data were coll

were drawn.

Ethnographers believe that it is only through identifying these multiple perspectives that a researcher can adequately describe and analyze what is happening in this classroom. Consequently, the ethnographer sees the members of a school community not as subjects, but as informants. The idea is to observe them, listen to them, and learn from them (Spradey, 1980). In other words, ethnographers seek to identify the categories that informants use to understand their world.

Qualitative Method Versus Quantitative Method

Since random sampling was not used in the selection of the target group, the research results of the qualitative method could not be generalized to encompass a large population. This is the major limitation of the qualitative method. However, the quantitative method also has its limitations such as Type-I error and Type-II error (Toothaker, 1986).

Type I error = rejecting the null hypothesis when it is true
= falsely rejecting null hypothesis
In other words, this is an error, a "false alarm," when we reject the null hypothesis when we should have accepted it.

Type II error = failing to reject null hypothesis when an alternative hypothesis is true (null hypothesis is false)
= falsely failing to reject a null hypothesis
In other words, this is an error, a "miss." (Toothaker, 1986)

Because both methods have their limitations, the issue is not which research method the researcher used, but rather how he designed the research settings, how the data were collected, how the analyses of the data were performed, and how conclusions were drawn.

Th

identify fa

conseque

translata

The

the respons

addition, if t

the informat

researcher t

researcher, a

Subje

college gradu

an interest in

The to

students, 2 gr

In orde

Michigan State

McLeod who is

The Validity of the Qualitative Method

The enthnographer believes that a study would be valuable as a case study used to identify factors for consideration. According to Goelz and Lecompte (1984), the consequence of this fact is that ethnographers must strive for comparability and translatability:

> Comparability requires that the ethnographer delineate the characteristics of the group studied or constructs generated so clearly that they can serve as a basis for comparison with other like and unlike groups. Translatability assumes that research methods, analytic categories, and characteristics of phenomena and groups are identified so explicitly that comparisons can be conducted confidently. (p. 22)

The assumption here is that comparisons are carried out by readers and that it is the responsibility of the researcher to provide the information to make that possible. In addition, if they desire, readers should be able to replicate the methods of the study from the information given in the report. This requirement makes it incumbent upon the researcher to present a full description of the site, the subjects, the role of the researcher, and the methods of data collection and analysis.

Subjects

Subjects in this study were volunteer students from middle school grades to the college graduate level and also included one elementary school teacher. Each expressed an interest in computer-based experiments in science.

The total number of subjects was 23: 4 high school students, 16 middle school students, 2 graduate students, and 1 elementary school teacher.

In order to recruit volunteers, the researcher received permission from Michigan State University and Lansing school districts in Michigan. Then Dr. Richard McLeod who is this author's advisor and committee chair called lots of schools to find students

Michigan

In

research.

welcome.

science to

were scien

The

pairs or wo

Therefore, s

individually

This

The PSL is a

understanding

together to pr

computer prog

The ha

temperature p

collect the inte

liquid, and 4) a

distance.

The PS

allowed users t

setups, 2) the

analysis menu e

students and teachers. Also this author sent letters through a student organization at Michigan State University to invite students to participate in this research.

In the letter, the researcher stated, "We need volunteers to participate in this research. All students from middle school level to the college students level are welcome. We would particularly like a range of science backgrounds from little or no science to science major." As a result, some subjects had very little science, and some were science majors.

The letter also stated, "The research site will be in your school. You may work in pairs or work individually, and the time will be arranged at your convenience." Therefore, some subjects came in pairs and worked together, and some worked individually.

Tool

This research used the IBM Personal Science Laboratory (PSL) program package. The PSL is a microcomputer-based laboratory designed to help students increase their understanding of science. The PSL consists of computer hardware and software working together to provide the science learning experience. The users did not need to know computer programming in order to use the PSL.

The hardware for the PSL consisted of an IBM computer and four sensors: 1) a temperature probe used to collect data about temperature, 2) a light probe used to collect the intensity of light, 3) a pH probe used to collect data about the pH value of a liquid, and 4) a distance probe that worked like a camera's auto focus sensor to measure distance.

The PSL software provided menus for users to control the PSL: 1) the main menu allowed users to select existing experiment set-ups or create their own experiment setups, 2) the run menu allowed users to perform their experiments, and 3) the analysis menu enabled users to analyze the data in different ways.

Table 3-

Subject
Subject
Subject
Subject
Subject
Subject
Subject
Subject
Subject
Subject
Subject
Subject
Subject 1
Subject 1
Subject 1
Subject 1
Subject 1
Subject 1
Subject 1
Subject 2
Subject 21
Subject 22
Subject 23

Table 3-1 Subjects' general information

	Year in school	Taken physics in school ?	Taken chemistry in school ?	Taken other science ?	Computer experience		
					above average	average	below average
Subject 1	11	No	Yes	Yes		X	
Subject 2	9	No	No	Yes		X	
Subject 3	11	No	Yes	Yes			X
Subject 4	11	Yes	Yes	Yes	X		
Subject 5	8	No	No	Yes			X
Subject 6	8	No	No	Yes			X
Subject 7	8	No	No	Yes			X
Subject 8	8	No	No	Yes			X
Subject 9	8	No	No	Yes			X
Subject 10	8	No	No	Yes			X
Subject 11	7	No	No	Yes		X	
Subject 12	7	No	No	Yes			X
Subject 13	7	No	No	Yes			X
Subject 14	7	No	No	Yes			X
Subject 15	7	No	No	Yes			X
Subject 16	7	No	No	Yes			X
Subject 17	7	No	No	Yes			X
Subject 18	7	No	No	Yes			X
Subject 19	7	No	No	Yes			X
Subject 20	7	No	No	Yes			X
Subject 21	Grad. student	Yes	Yes	Yes	X		
Subject 22	Grad. student	Yes	Yes	Yes	X		
Subject 23	Teacher	No	Yes	Yes		X	

cool wi

you let

phenom

objects

a const

affect co

PSL EX

subjects

The softw

S

experime

the PSL h

to use the

D.)

The

Michigan Sta

computer lab

no classes we

Appendix C fo

The res

science lab inc

the small room

closing a door.

diagram.)

A simple example concerning the use of the PSL follows: A hot object tends to cool when you stop heating it. A cold object taken out of the freezer tends to warm up if you let it stand at room temperature. These statements seem obvious. To explore the phenomena more deeply, one may raise questions such as the following: Are all the objects cooling down or heating up with the same speed? Does the temperature change at a constant rate? How do factors such as wind, container shape, container materials, etc., affect cooling? The experimenters or students could use the temperature probe and the PSL EXPLORER program to discover facts about how objects cool and warm up. Some subjects might want to find the relationship between the temperature and time needed. The software provides graphic displays of the changes for easy analysis.

Some printed materials which guided subjects to perform temperature experiments through a step-by-step procedure were given to the subjects to accompany the PSL hardware and software. These printed materials assisted subjects to learn how to use the PSL while they were doing their own investigations. (These are in Appendix D.)

Sites

The research sites were in Lansing school district in Michigan and also at Michigan State University. The research site that the high school provided was a computer lab next door to a physics lab. At the time subjects participated in this study, no classes were going on in that room; therefore, there was no interference. (See Appendix C for diagram.)

The research site that the middle school provided was part of a science lab. The science lab included one big room and a small room, and the observation was conducted in the small room. Subjects sometimes separated this small room from the science lab by closing a door. As a result, this room had no interference. (See Appendix C for diagram.)

was in a

in the e\

for diag

Th

to learn ho

the PSL.

experimen

Creativity h

form a unio

All t

continued to

Leve

The research site that the graduate students chose at Michigan State University was in a computer lab. This lab was not used for teaching at that time. It was very quiet in the evening and on weekends, and there was no interference at all. (See Appendix C for diagram.)

Subjects' Activities

The major subjects' activities were at three levels. The first level was designed to learn how to use the PSL. The second level was designed to promote the application of the PSL. Promoting application here means that students designed their own experiments with the PSL. The third level was designed to promote creativity. Creativity here means that the students were able to combine parts of the experiments to form a unique or novel solution to a problem.

All the subjects completed the first level of the experiment. Some subjects continued to complete the second level and third level of the experiments.

Level one: Learning how to use the PSL

In this level, subjects viewed a ten-minute introductory video of the PSL first and then followed a step-by-step procedures to complete the following experiments:

(1) A simple temperature experiment (using an existing experiment template).

(2) Creating a temperature experiment (creating a new experiment template).

(3) Running a two-probe experiment

L

Sub

they worked

All p

middle scho

level. The

participants s

(IBM's versi

Bogda

research:

Level two: Designing the subjects' own experiment

Subjects selected any kind of the PSL probes, such as temperature, Motion , pH, or light probes, to design their own experiment. They explored the potential application of the PSL to meet their needs.

Level three: Theoretical approximation and analysis

Subjects used additional computer application programs, for instance, MS-WORKS spreadsheets, to do theoretical approximation and then found an equation that represents the data collected; in some cases, they used different calculation functions to perform more complex analyses of the experimental data. On this level, subjects were expected to explore and discover something new to them.

Subjects worked together in pairs or individually. If two subjects came together, they worked together. If a subject came individually, he/she worked alone.

All participants completed the first level. Four high school students, 5 of 16 middle school students, and the elementary school teacher participated in the second level. The 2 graduate students successfully completed the third level. All the participants stated that they enjoyed learning and using the Personal Science Laboratory (IBM's version of MBL).

Data Collection

Bogdan and Biklen (1982) identify five major characteristics of qualitative research:

1. Qualitative research has the natural setting as the direct source of data, and the research is the key instrument.
2. Qualitative research is descriptive.

T

and how

Subjects

T

(for high

student s

science l

were no t

needed in

no control

participant

sense that

The Resea
Analyst, a

The

researcher

personal as

of view. Th

Finally, the

considered

As n

number of q

3. Qualitative researchers are concerned with process rather than simply with outcomes or products.

4. Qualitative researchers tend to analyze their data inductively.

5. "Meaning" is of essential concern to the qualitative approach. (p. 27)

The following is a description of the key characteristics of qualitative research and how each was implemented in this study.

Subjects Were Observed in a Natural Setting

The observations of this study were conducted in a high school science laboratory (for high school subjects), a laboratory at Michigan State University (for graduate student subjects), a middle school science laboratory (for middle school subjects), and a science laboratory in an elementary school (for an elementary school teacher). There were no time limits for activities; subjects quit at any time or stayed as long as they needed in order to complete their experiments. The researcher was an observer and took no control over students and variables so that he could understand the situation from a participant's perspective. However, this study was not completely naturalistic in the sense that an observer was just watching as subjects' performed experiments.

The Researcher Was an Observer, Interviewer, Analyst, and Writer--the Key Instrument

The research design, data collection, analysis, and reports were completed by this researcher (this author). The researcher did his best to recognize and filter out personal assumptions and biases in order to understand an event from the subject's point of view. The researcher also collected data on thoughts and feelings during the study. Finally, the data collected from subjects and the researcher's thoughts and feelings were considered in analyzing data.

As noted in Chapter one, this study was designed to investigate and assess a number of questions about the impact of the PSL program on subjects' learning of physics

how eac

the dive

tailored t

Appendix

observer

Fo

provided

experimen

that some

of the term

the subjec

by solving

Upo

questions i

subjects' de

increase or

when you b

in hot wate

step experim

the compute

hypothesis f

PSL?"

Base

among the s

matter knowl

physics concepts. In order to gather answers to these questions, the researcher observed how each subject approached the PSL program, and he interviewed each of them. Due to the diversity of the subjects, each was interviewed with a set of particular questions tailored to his or her experiences. Some questions were the same for all subjects. (See Appendix E.)

The following examples illustrate how the researcher interacted in the role of observer and interviewer.

For the first level of the subjects' activities, subjects followed the PSL manual provided by the IBM computer company in order to complete three temperature experiments. These three experiments used step-by-step procedures. It was assumed that some subjects would get "stuck" (have problems performing the tasks) due to some of the terminology and the gap between sequential steps. The researcher observed how the subjects gained both computer experience and subject-matter knowledge of physics by solving the problems.

Upon completion of the first level of activities, the researcher asked some questions in order to stimulate thinking. Responses to the questions reflected the subjects' depth of thinking. Examples of questions include, "Does the temperature increase or decrease when you blow on the probe? Is this different from what you feel when you blow on your skin? Why? If a person removes both temperature probes (one in hot water and the other in cold) at the same time (after 10 seconds in the step-by-step experiment that is entitled 'Running a Two-Probe Experiment'), what happens on the computer screen? How do you explain these results? Can you formulate a hypothesis from the computer graphs? How will you test your hypothesis by using the PSL?"

Based upon subjects' responses, the researcher identified the major linkages among the subjects' responses, their computer experiences, and their in-depth subject-matter knowledge.

probe t

intervie

How are

by using

function

the clock

the sum

F

approxim

is the the

used in fi

approxima

collected?

program?

Data Colle

The

(1982) ide

capturing s

Graphs we

behaviors a

support des

The

product: Ma

generate an

study did nc

At the second level of subjects' activities, for those subjects who use the motion probe to perform a simple pendulum experiment, the researcher asked some follow-up interviewing questions such as, "What factors affect the period of the simple pendulum? How are you going to figure out the relationship between the period and the other factors by using the PSL? What do the new computer graphs mean when you choose a calculation function in the PSL? Why can a simple pendulum be used to make a pendulum clock? If the clock goes faster in the winter, how will you adjust it? If the clock goes slower in the summer, how will you adjust it?"

For the third level of subjects' activities, if a subject performed a theoretical approximation, the following questions were asked for the follow-up interview, "What is the theoretical foundation of this approximation? Could you state the strategy that you used in finding the approximation equation this way? Do you feel confident that the approximation equation you obtained adequately represents the real-time data you had collected? Why? Do you feel confident when you use the calculations in the PSL program?"

Data Collected in This Study Were Descriptive

The second characteristic of the qualitative research that Bogdan & Biklen (1982) identified was descriptive. Verbal descriptions were the major medium for capturing subjects' behaviors and perceptions as they experienced each experiment. Graphs were used when verbal descriptions were not enough to capture subjects' behaviors and perceptions. Numbers such as percentages were used primarily to support descriptions of events and behaviors.

The major concern of this researcher was the process rather than outcomes or product: Many qualitative studies have demonstrated that focusing on process can generate an understanding of how the outcome occurs (Bogdan & Biklen, 1982). This study did not include any paper-and-pen examinations, and subjects did not have time-limits to

other w

they co

research

complete

and how

method

subjects

Data We

Th

suited to

quantitat

students

research f

up" appro

among sub

Meaning W

Fina

primary foc

subjects th

role of the

reporter. H

circumstanc

not effect th

school subje

limits to complete their tasks. The approach to the PSL was an open-ended process. In other words, subjects could do what they were able to do with the PSL environment, and they could do as much as they were able to do. During the observation times, the researcher focused on how subjects approached the PSL, what kinds of tasks they completed, what new phenomena they discovered, why they used particular approaches, and how their attitudes might have changed. This study did not compare the traditional method of learning in terms of how much subjects' scores changed and which methods subjects used to learn faster.

Data Were Analyzed Inductively

The fourth characteristic of qualitative research, analyzing data inductively, was suited to this study. This researcher felt that previous research on the MBL used a quantitative method and measured final scores (i.e., emphasized how the MBL improved students' learning specific physics concepts) and did not generate a theory to predict the research foci, which were emphasized on the processes in this study. Instead, a "bottom up" approach like inductive reasoning would help this researcher to identify linkages among subjects.

Meaning Was of Essential Concern

Finally, the fifth characteristic, a major concern with "meaning," was the primary focus in this study. The researcher was interested in understanding how subjects thought and understood the experimental results. As mentioned earlier, the role of the researcher in this study was as an observer, interviewer, analyst, and reporter. He was not a helper, nor was he an instructor. However, under some circumstances, in order to understand "meaning," clues were provided, if those clues did not effect the research results. For example, the researcher provided a clue to middle school subjects so that they could answer the pendulum clock questions, "If the clock goes

faster in
summer
students
were co
making a
making a
questions
period an
temperatu
reasoning
The secon
heat expa
these two
"meaning"
results or
longer or s
understand
experiment
had difficult
pendulum.
answer the
findings to p
students.

As d
approach ar
the data coll

The s

faster in the Winter, how do you adjust it?" and "If the clock goes slower in the summer, how do you adjust it?" This was because the five subjects of middle school students were not able to make a connection between period and temperature when they were confronted with these two questions. However, subjects who had difficulty in making a connection between period and temperature were not necessarily incapable of making a connection between the period and the length of the pendulum. These two questions involved three different reasoning processes: 1) making a connection between period and pendulum length, 2) making a connection between pendulum length and temperature and 3) making a connection between period and temperature. The first reasoning process indicated whether the subjects understood the experimental results. The second reasoning process indicated whether the subjects had prior knowledge with heat expansion. The third reasoning process involved the subjects' ability to combine these two physics concepts to arrive at a conclusion. In order to investigate the "meaning" of whether the five middle school students understood the experimental results or other reasons, the researcher provided a clue, "Will the pendulum become longer or shorter when the temperature is higher?" This clue helped the researcher understand the "meaning" that these five middle school students understood the experimental results: the longer the pendulum, the longer the period. However, they had difficulty in making the connection between the temperature and the period of a pendulum. This did not mean that they were not able to apply the experimental results to answer the questions. It only indicated that their ability to link the experimental findings to prior knowledge like heat expansion was different than those of high school students.

As demonstrated above, Bogdan & Biklen's five characteristics of the qualitative approach are suited to this study. This study applies these five characteristics to guide the data collection.

The specific methods used in data collection for this research are as follows.

questi

record

S

surpris

T

Tesc

process in th

All the subjects were asked to complete a survey questionnaire which included questions about their prior computer experiences and their subject-matter knowledge.

The major data collection techniques were observation, note taking, cassette tape recordings, and interviews.

Subjects were encouraged to reflect on their activities by writing notes about surprising results and how the experiments relate to their own experiences.

Methods of Data Analysis

Tesch (1990) identified ten principles and practices of qualitative analysis:

1. Analysis is not the last phase in the research process; it is concurrent with data collection or cyclic.
2. The analysis process is systematic and comprehensive, but not rigid.
3. Attending to data includes a reflective activity that results in a set of analytical notes that guide the process.
4. Data are 'segmented' i.e., divided into relevant and meaningful 'units.'
5. The data segments are categorized according to an organizing system that is predominantly derived from the data themselves.
6. The main intellectual tool is comparison.
7. Categories for sorting segments are tentative and preliminary in the beginning; they remain flexible.
8. Manipulating qualitative data is an eclectic activity; there is no one 'right' way.
9. The procedures are neither 'scientific' nor 'mechanistic.'
10. The result of the analysis is some higher-level synthesis. (Tesch, 1990 p. 95)

Tesch's ten principles were used as an umbrella to cover the data analysis process in this study. The specific procedures were as follows:

written

Comme

a comp

S

T

categorie

the data.

Tesch's s

two aspe

vertical c

had made

were app

Ste

The

codes whic

Ste

This

in this stud

what extent

such as the

transcription

performance

Step 1: Review the data

The data analysis began as soon as this study started. Throughout the study, hand written field notes from observations and audio tapes were processed into a computer. Comments on each subject and comparisons with other subjects were also processed into a computer.

Step 2: Identify key linkages

The collected data were repeatedly read to search for possible trends or categories. "Relevant" and "meaningful" were two major considerations in organizing the data. The main intellectual tool to identify key linkages was "comparison." Applying Tesch's sixth principle in this study, this researcher compared the data of subjects in two aspects: 1) horizontal comparison (i.e., comparing one subject with the others), 2) vertical comparison (i.e., comparing subjects with themselves to see what progress they had made). In some situations, the combination of horizontal and vertical comparison were applied.

Step 3: Formulated, tested and revised assertions

The initial insights which were formulated in step two were then turned into codes which were applied to the data. Codes that did not seem to fit were modified.

Step 4: Write a report--this dissertation

This step consists of a comprehensive review and comparison of all data collected in this study. Then the findings were generated. For example, in order to determine to what extent the subjects learned physics concepts, the researcher reviewed all data, such as the completed survey questionnaires, observation notes, audio tapes transcriptions, and interview notes. Then he compared all subjects' responses and their performances in order to ascertain to what extent subjects understood the experimental results

drawn

researc

questio

subjects

MBL pro

the gap

results and what further reaction they had. Based on this data analysis, findings were drawn.

Because this study included 23 subjects, 3 levels of subjects' activities and 9 research questions, the organization of the data report emphasized each research question. Under each research question, each subject's data were presented by level of subjects' activities.

Summary of This Chapter

The qualitative method was used in this study in order to assess the impact of the MBL program on physics concepts and to determine whether it had the potential to bridge the gap between academic learning and real life.

The data are presented in Chapter four.

school, a

study, in

students

1993 and

Table 4-

subjects

Th

may be he

much like

At the sam

Students n

CHAPTER IV

DATA PRESENTATION, DISCUSSION AND FINDINGS

Overview of the Data Presentation

This study took place at one high school, one middle school, one elementary school, and at Michigan State University. Twenty-three subjects participated in this study, including four high school students, sixteen middle school students, two graduate students, and one elementary school teacher. The data were collected between November 1993 and March 1994. There were three levels of subject activities in this study. Table 4-1 summarizes their purposes, describes the activities, and identifies how many subjects were at each level.

Throughout this chapter, references are made to PSL graphs and PSL tables. It may be helpful to know that the data collected by PSL proofs are stored in a data table, much like a student might produce when collecting data using more traditional matters. At the same time, the PSL software produces a graphical representation of these data. Students may use the data in either form, table or graph.

Table

Leve
Level
Level

Ta

each sub

Table 4-1 Purpose, activities and how many subjects at each level:

	Purpose	Activities	Number of subjects
Level one	Learning how to use the PSL.	Subjects were asked to follow prescribed procedures to complete three temperature experiments: 1) Simple temperature experiment. 2) Creating a temperature experiment. 3) Running a two-probe experiment.	23
Level two	Promoting application of the PSL.	Subjects chose probes, designed their experiment set-ups and performed experiments on their own. There were no prescribed procedures.	12
Level three	Promoting creativity.	Subjects explored the usage of the PSL as far as they could for the topic in which they were interested.	2

Table 4-2 summarizes who participated at each level and how many experiments each subject completed at each level.

Table

Exp

Level
- S
- C
- R

Level t
- Si
- Ma
- Ca
- PH

Level th
- Ap
e
- Exp
c

Th

interviews

study was

learning ph

Sor

meanings

Cor

study, and

presented b

section of th

followed by

The

Table 4-2 Experiments, grade level and participation:

Subject's education & Subject number / Experiments	High school students				Eighth grade students						Seventh grade students										Graduate students		Teacher
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Level one:																							
• Simple temperature experiment.	x	x	x	Was late	x	x	x	x	x	x	x	Was late and left early in level one	x	x	x	x	x	x	x	x	x	x	x
• Creating a temperature experiment.	x	x	x		x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
• Running a two-probe experiment.	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
Level two:																							
• Simple pendulum experiment.	x		x	x							x		x	x					x	x	x	x	x
• Mass-Spring experiment.	x		x	x							x		x	x					x	x	x	x	
• Calculation	x		x	x							x		x	x					x	x		x	
• PH experiment.	x	x																					
Level three:																							
• Approximation for experimental data.																					x		
• Exploring advanced calculation																						x	

The data presented in this chapter are derived from audio tape transcriptions, interviews, and observational field notes by the author. The primary purpose of this study was to investigate the impact of the Microcomputer-Based Laboratory (MBL) on learning physics concepts as was stated in Chapter one.

Some examples are presented more than once, because they have different meanings when viewed from different perspectives.

Considering there were 23 subjects and three levels of subject activities in this study, and the author reverted to the ten research foci listed in Chapter one, the data are presented by use of these research foci. Each research focus is examined in a separate section of this chapter. Each section begins with the presentation of the data. It is followed by a discussion. Based on the data and discussion, findings are made.

The following are the data presentation, discussion, and findings.

Re

Level o

were a

on the

Why?

question

question

Table 4-

Subj (Year in
Subject (11)
Subject (9)
Subject (11)

Research Foci One: To what extent subjects learn physics from the PSL program?

Level one:

In the Simple Temperature Experiment (Appendix D) of level one, all subjects were asked two questions: 1) Does the temperature increase or decrease when you blow on the probe? 2) Is this different from what you feel when you blow on your skin? Why?

Table 4-3 shows how subjects who had not taken physics responded to these two questions, and Table 4-4 shows how subjects who had taken physics responded to the questions.

Table 4-3 Responses from subjects who had not taken physics:

Subject (Year in sch.)	Question 1: Does the temperature increase or decrease when you blow on the probe?	Question 2: Does this differ from what you feel when you blow on your skin? Why?
Subject 1 (11)	It increased slightly but not very much.	Ah, you feel cool when you blow on your skin......basically you don't have a cool effect. (He didn't answer why.)
Subject 2 (9)	Increases.	The temperature in the room is cold, when blow on it, it gets higher......
Subject 3 (11)	It increases.	When you blow on your skin, it is colder. Why? why? Maybe because your body temperature is higher than your breath, something like this, is that right? I really don't know why. It could be ......Hm, the probe......I don't know if it has the same temperature like your

Table

Sub Sub
Sub Sub (
Subje Subje (
Subjec Subjec (7
Subject Subject (7)
Subject Subject (7)
Subject Subject (7)
Subject Subject (7)
Subject (Teache

Table 4-3, continued

		body. It would be different. I don't know the exact answer why.
Subject 5 & Subject 6 (8)	Subject 5: It went down. when I blew on it, it went down a little lower than was.	Subject 5: That made the skin kind of cold.
Subject 7 & Subject 8 (8)	Subject 7: It decreased. Subject 8: No, it can go up, increased. Subject 8: Yes.	Subject 8: Yes, your body's temperature is warmer than the room temperature.
Subject 9 & Subject 10 (8)	Subject 9: It increased. Subject 10: It increased.	Subject10: Yes, there is a difference, because my skin feels cool, and it goes up. Subject 9: Mn hm. Subject10: My skin is hot, and the air is cold.
Subject 11 & Subject 12 (7)	Suject 11: Increased.	Suject11: Yes, there is a difference when you blow on your skin, because you feel colder, but a......I am not sure why. It is warmer in the air but is cooler in the skin.
Subject 13 & Subject 14 (7)	Subject 13: From here it increased. from there it decreased.	Subject 13: I feel cold.
Subject 15 & Subject 16 (7)	Subject 15: Increased.	Subject 15: I feel cold.
Subject 17 & Subject 18 (7)	Subject 18: Decreased.	
Subject 19 & Subiect 20 (7)	Subject 20: Increased.	Subject 20: Yes.
Subject 23 (Teacher)	Increased.	Different. Because of evaporation.

Table

Su (Year
Subj (1
Subje (Gradu
Subject (Graduat

The

graphs tha

conflict be

Almost all

that the ter

temperature

Table 4-4 Responses from subjects who had taken physics:

Subject (Year in sch.)	Question 1: Does the temperature increase or decrease when you blow on the probe?	Question 2: Does this differ from what you feel when you blow on your skin? Why?
Subject 4 (11)	(Subject 4 was supposed to work with Subject 3, but Subject 3 was late and missed this activities.)	
Subject 21 (Graduate St.)	Increased.	There is a difference. This is because the effect of evaporation. When I blew on the temperature probe, the temperature increased a little bit at the beginning, then it started decreasing. The same amount of heat from each blow might cause less temperature incease on my hand because my hand is much bigger than the temperature probe. In other words, the temperature increased so little that my skin was unable to detect that small temperature change on my hand.
Subject 22 (Graduate St.)	It increased.	The difference is due to the effect of evaporation. The temperature only increased for a short time when I blew on the temperature probe, then the temperature started going down. My skin was probably not sensitive enough to respond to this short time change.

The subjects answered these two questions based on the real-time computer graphs that they viewed by using the PSL. Most of the subjects were confronted with a conflict between their intuitive feeling and the PSL graphs on the computer screen. Almost all of the subjects stated that when they blew on their skin, it felt cool (it seemed that the temperature decreased), but when they blew on the temperature probes, the temperature increased slightly for a short time, then started decreasing. This conflict challe

answe

differe

experi

experin

the con

the con

tempera

blew on

"Why?

breath,

the prob

different

explain

breath",

reasonab

S

contradict

terms of t

increase w

the tempe

started to

less tempe

temperatur

was unable

this differen

"The tempe

challenged them. Only two of the subjects could immediately suggest a reasonable answer to explain why this conflict occurred, but most realized that there was a difference. Since this was a real-time experiment (i.e., the data are being taken as an experiment progresses, Sneider & Barber 1990), they accepted the results of the experiment that the PSL displayed on the computer screen. Since no one suggested that the computer data were wrong, it seemed as though they trusted both their feelings and the computer data. Another problem was how to explain this conflict---the temperature increased when they blew on the probe, but they felt a coolness when they blew on their skin. This conflict stimulated their thinking. Subject 3's response was: "Why? Why?...... Ah, maybe because your body temperature is higher than your breath, something like this, is that right? I really don't know why. It could be......Hm, the probe ......I don't know if it has the same temperature like your body. It would be different. I don't know the exact answer why". She tried to use her past experience to explain the difference, "maybe because your body temperature is higher than your breath", however, she was not satisfied with her explanation. She could not find a reasonable explanation for this phenomenon.

Subjects who had a physics background (Table 4-4) understood the contradiction. Subjects 21 and Subject 22 explained the cooling effect on the skin in terms of the effect of evaporation. They had different assumptions for the temperature increase when they blew on the temperature probe. Subject 21 said: "When I blew on the temperature probe, the temperature increased a little bit at the beginning, then started to decrease. The same amount of heat from each blowing on my skin might cause less temperature increase on my hands because my hand is much bigger than the temperature probe. In other words, the temperature increased so little that my skin was unable to detect that small temperature change on my hand." Subject 22 explained this difference in terms of the concept of changing rate of the temperature. He stated: "The temperature only increased for a very short time, when I blew on the temperature probe.

enoug

He dic

tempe

Discuss

experim

find rea

tempera

tempera

tempera

their sk

differen

Fr

subjects

the probe

of the su

that poss

and Subje

blew on th

detected b

probe, then the temperature started going down. My skin was probably not sensitive enough to respond to this short time change."

Subject 23 also explained the cooling effect on the skin as an evaporation process. He did not try to explain why the temperature increased when he blew on the temperature probe.

Discussion of the Simple Temperature Experiment

From the subjects' responses to these questions, it appeared that this simple experiment created a problem which was more complex than expected. Subjects did not find reasonable answers to explain the difference between their observation of the temperature probe and what they felt on their skin. However, it showed that the simple temperature experiment helped most of the subjects recognize a discrepancy (the temperature increased when they blew on the probe and felt cool when they blew on their skin) and question, "why." According to Thornton, the process of discovering this difference is engaging students in the learning process.

> Students gain first-hand knowledge of physical phenomena, construct for themselves the theories necessary to understand the physical world and formulate their own questions, further engaging them in the learning process. To alter misconceptions that were first generated by interaction with the physical world requires additional interaction. (Thornton, 1987)

From their first-hand data of the Simple Temperature Experiment, most of the subjects formulated their own question---the temperature increased when they blew on the probe and it felt cool when they blew on their skin, "why?" This conflict engaged 8 of the subjects to think about the "why". Subject 3, Subject 8 and Subject 10 thought that possibly the body temperature was higher than the room temperature. Subject 21 and Subject 22 concluded that their skin did not feel the temperature increase (as they blew on their skin) because the temperature increase was too little and too fast to be detected by their skin. Additional interaction was needed in order to test Subjects 3, 8, 10, 21 and 22's hypotheses. It is possible that if there were a teacher present to help stimulate questions and guide students' subsequent interaction, students could have provided a correct interpretation of the data.

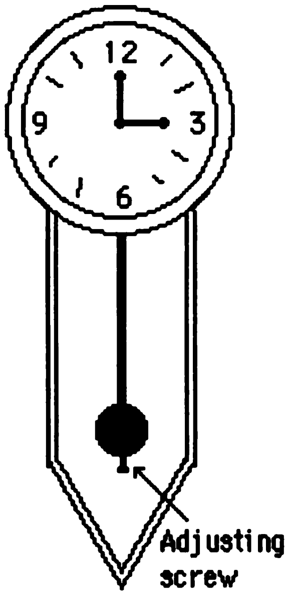
> Although a well designed measurement tool can help, it certainly is not enough to ensure that science learning takes place, in most situations. Accompanying curricula (usually printed materials written for particular age and skill levels) guide students though initial investigations and on to their own investigations. In addition, the teacher using such materials must encourage, or at least not actively discourage, an inquiry-based approach to science learning. (Thornton, 1987)

The findings from the Simple Temperature Experiment supported Thornton's suggestion-- further guidance and additional exploration may be necessary to test their hypotheses in order to assist students to find a reasonable explanation.

Level Two (Choices Provided)

Only 11 of the 23 subjects experimented with level two. Subjects might choose probes to perform their experiments. Some subjects performed simple pendulum, Mass-Spring Oscillation and pH experiments. Some subjects only performed the pH experiment. In total, ten subjects performed the simple pendulum experiment, eight subjects measured the period of a Mass-Spring Oscillation, nine subjects explored the calculation functions and two subjects performed the pH experiment. This section deals first with those who chose the simple pendulum experiment. The measuring results of the Mass-Spring Oscillation will be reported in research question two. The results of exploring the calculations will be reported in research question four. Subjects 1 & 2's approaches in the pH experiment will be discussed under research question seven. Subjects who performed the simple pendulum experiment were provided some instruction in order to help them to get better pendulum graphs. Some clues were provided for middle school subjects to help them make connection between heat expansion and the length of the pendulum. They had difficulty making this connection without assistance.

Subjects who performed the simple pendulum experiment were expected to answer the following questions.



Qustions about the pendulum clock:

Question 1: Why can a simple pendulum be used to make a pendulum clock?

Question 2: If the clock goes fast in the Winter, how will you adjust it?

Question 3: If the clock goes slow in the Summer, how will you adjust it?

Figure 4-1 Question about the pendulum clock

Note: None of the subjects asked whether the pendulum clock was located in a place where the temperature was constant or whether the material of the pendulum rod contracted when heated. It then appeared that they accepted the assumptions: 1) the pendulum clock is in a place where the temperature is lower in the Winter than in the Summer. 2) the material of the pendulum rod expands when heated.

Table 4-5 (subjects who had not taken physics) and Table 4-6 (subjects who had taken physics) list their responses after the experiments.

Ta

(Y
S
S
Sa
Sub Sub
Sub Subj (
Subj (Tea

Table 4

Sub (Year
Subje (1
Subje (Gradua
Subjec (Gradua

Table 4-5 Answers from subjects who had not taken physics:

Subject (Year in sch.)	Answered Question 1 correctly? (Yes or No)	Answered Question 2 correctly? (Yes or No)	Answered Question 3 correctly? (Yes or No)
Subject 1 (11)	Yes	Yes	Yes
Subject 3 (11)	Yes	Yes	Yes
Subject 11 (7)	Yes	Yes	Yes
Subject 13& Subject 14 (7)	Yes Yes	Yes Yes	Yes Yes
Subject 19& Subject 20 (8)	Yes Yes	Yes Yes	Yes Yes
Subject 23 (Teacher)	Yes	Yes	Yes

Table 4-6 Answers from subjects who had taken physics:

Subject (Year in sch.)	Answered Question 1 correctly? (Yes or No)	Answered Question 2 correctly? (Yes or No)	Answered Question 3 correctly? (Yes or No)
Subject 4 (11)	Yes	Yes	Yes
Subject 21 (Graduate St.)	Yes	Yes	Yes
Subject 22 (Graduate St.)	Yes	Yes	Yes

All of the subjects (Note: most of the subjects had not taken a physics class at that time) were able to answer these three questions correctly. This could be because the real-time computer graphs, their measurement and their calculations helped them discover the correct answers. (Research question 2 will provide more detail.)

To perform the simple pendulum experiment, subjects followed an instructional guide (not required) with the following steps.

1) Set up the experiment as follows

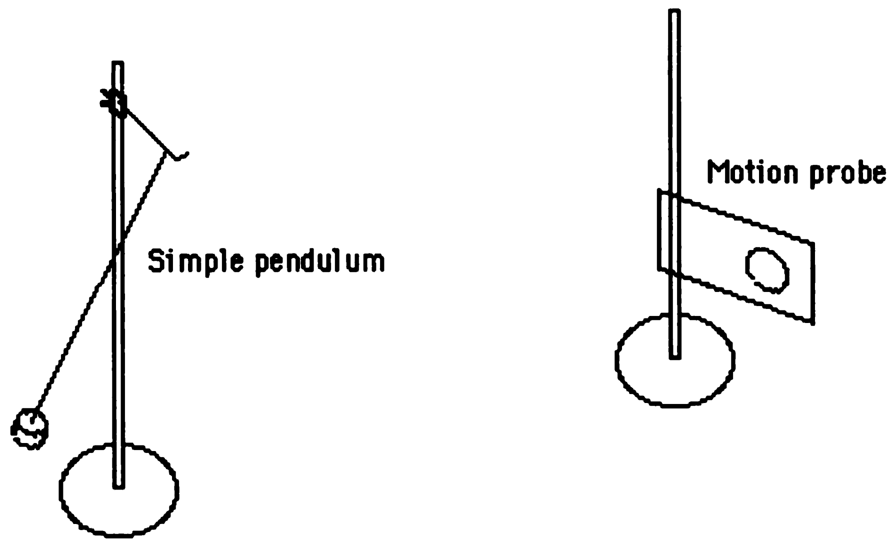


Figure 4-2 Simple pendulum experiment set-up

2) Choose an appropriate experiment set-up from the PSL and start the swing of the simple pendulum.
3) Start collecting data. If the computer screen shows the following graphs, reduce the swing and start it over.

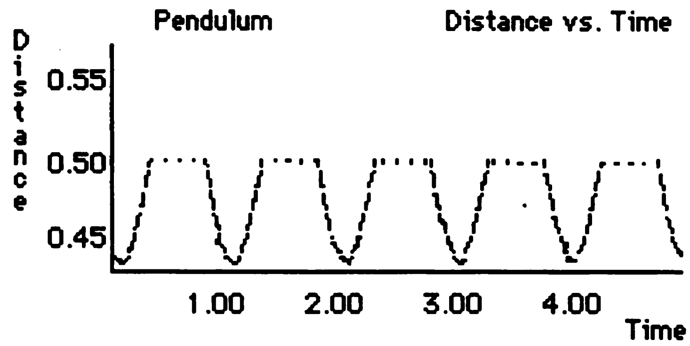


Figure 4-3 Incorrect pendulum wave

4) Repeat step 3 until the computer screen shows graphs similar to the following.

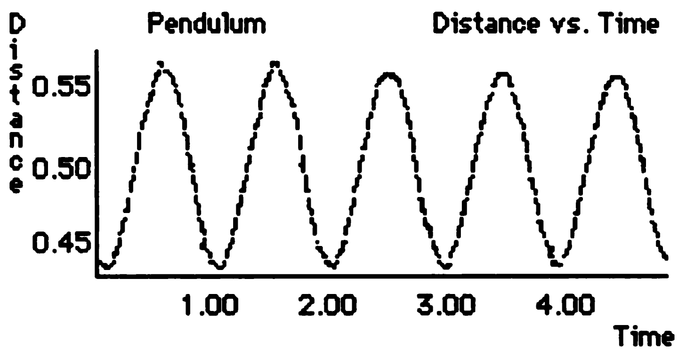


Figure 4-4 Correct pendulum wave

5) From the computer graphs, find out how long it takes for each swing.

6) Make a new simple pendulum (e.g. half length or quarter length) and repeat step 3 to step 5.

Note: In order to make a new pendulum, subjects 1, 3 and 4 made a new pendulum by folding the length of the pendulum. When subjects 19 and 20 performed the simple pendulum experiment, they tied a knot on the string (half length, quarter length). The researcher thought that it would be a good idea to keep the knots on the string in order to compare other subjects' the i

differ

acco

exper

exper

20 se

their c

selecte

learne

Tempe

or crea

by mea

screen.

time int

suggest

pendulu

stated th

pendulur

able to u

experiment results. Since that time, all subjects made a new pendulum by simply hanging knots on the stand (their experimental results are showed in Table 4-7).

Since this instruction suggested a way for subjects to alter the pendulum lengths, the interesting observation is not their similarity in experimenting with pendulums of different lengths. Of greater interest is their similarity in applying the PSL to accomplish their experiments.

There were commonalties on how each subject approached the simple pendulum experiment with the PSL.

• Subject 1, and the pair of subjects 3 &4 selected the Distance & Velocity experiment in a pre defined set-up. Paired subjects 13 &14 and paired subjects 19 & 20 selected Distance vs. Time experiment set-ups. Subjects 11, 21 and 22 created their own different experiment set-ups. However, all the experiment set-ups that they selected or created met the needs of their experiments very well (Note: all subjects learned how to select experiment set-ups or create experiment set-ups from the Temperature experiment). Their success indicated that each subject was able to choose or create an appropriate experiment set-up to collect data.

• Subjects 1, 3, 4, 11, 19, and 20 determined the period of the simple pendulum by measuring the time interval between two successive peaks from the graphs on the screen. Subjects 13 and 14 measured the period of the simple pendulum by finding the time intervals between two adjacent troughs. Their performances in finding the periods suggested that they realized each sine wave on the computer screen corresponded to one pendulum swing. Subjects 21, 22 and 23 did not complete the measurements. They stated that they had prior knowledge about the pendulum and knew how to adjust the pendulum clock.

• All subjects in the simple pendulum experiment demonstrated that they were able to used the Graph command and the arrow key to determine the corresponding time of e

usi

For

leve

the s

Sub

conc

Subje

was 2.

PSL ac

the pen

Subject

the pen

one mo

seconds

measure

further,

not corre

deflection

Subject 3

of each peak or trough (Note: In the Temperature experiments, all subjects practiced using the Graph command and the arrow key to find the exact temperature on the graphs. For further information, see Appendix D). This suggested that subjects in the second level were able to apply what they had learned from the first level.

The following examples state some differences concerning how subjects completed the simple pendulum experiment.

Subject 1 (level two experiment)

Upon completing his simple pendulum experiment, Subject 1 drew the following conclusions:

> The speeds (Distance VS. Time and Velocity VS. Time) are the same, but ah, like the distance of rope, the different length of rope, the shorter one is shorter (period), I mean the time, and the wider (the wave) is longer......if the length (of rope) is shorter, the period is shorter (the researcher asked: Does it mean the pendulum moves fast?) Oh no, (after he compare the waves) ...... I guess it moved fast.

Subject 3 & Subject 4 (level two experiment)

From the first graphs, Subjects 3 &4 discovered that the period of the pendulum was 2.10 seconds. To see if the period kept the same time for a short time, they ran the PSL again to collect another set of data. From the second graphs, they found the period of the pendulum was 2.00 seconds. Because 2.00 seconds was shorter than 2.10 seconds, Subject 4 guessed: "While the pendulum was swinging the amplitude was reducing, so the pendulum moved faster and faster." To test Subject 4's conclusion, they ran the PSL one more time. From the third graph, they discovered that the period was 2.025 seconds. If Subject 4's first conclusion was correct, the period obtained from the third measurement should have been less than 2.00 seconds. Since the amplitude was reduced further, the pendulum should have moved faster. Since Subject 4's first prediction was not correct, she made another guess: "We couldn't find the exact points of the peak deflections from the graphs." To find a more accurate way to figure out the period, Subject 3 explored the computer's top menu. As Subject 3 opened the Table from the top m

w

sec

two

accu

from

that t

by me

further

Subjec

menu, a window showed the data of Time, Distance and Velocity. Subject 4 tried a new way to measure the period from the Data Table.

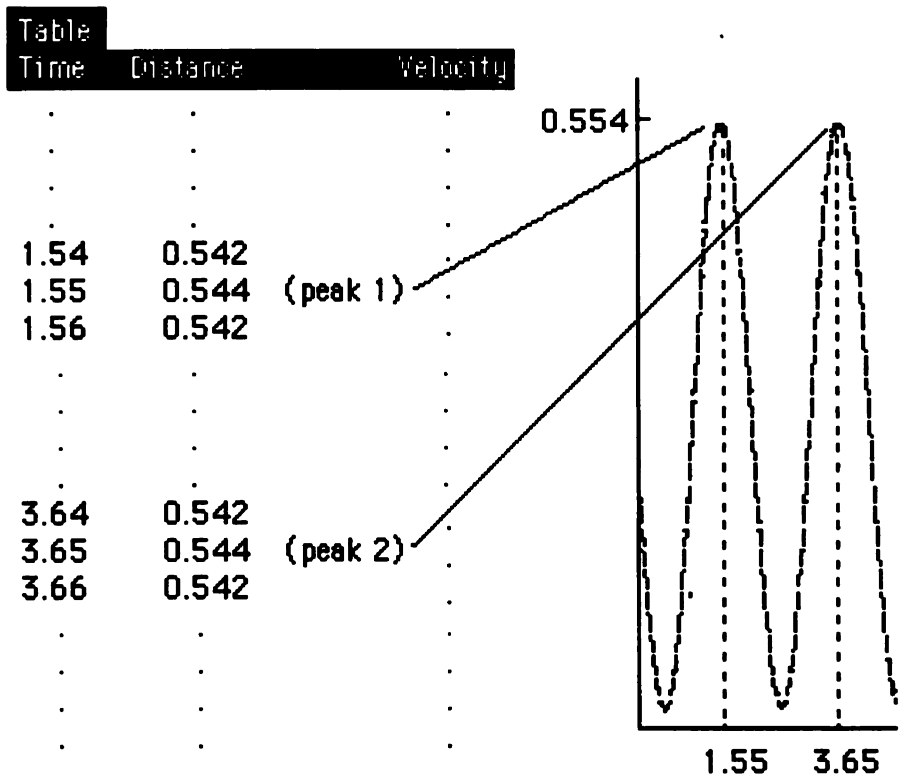


Figure 4-5 Subject 4's idea in measuring the pendulum period

From Figure 4-5, Subject 4 found the corresponding time of peak 1 was 1.55 seconds and the time corresponding to peak 2 was 3.65. The time interval between these two peaks was

3.65 -1.55 = 2.10 (seconds)

It was interesting to note that their measurement from the graphs was as accurate as the result they found from the Data Table. Because the results they obtained from the data table matched their measurements from the graphs, Subject 4 concluded that the differences of the time intervals between each of the two peaks were not caused by measurement errors on the computer graphs. She tried to find other ways to do further investigations, but she could not think of any another idea at that time.

Subject 11 (level two experiment)

foll

pen

mad

8.05

answ

were

had

secc

time

almcs

exper

calcula

adjace

accura

Subjec

two ad

measur

make n

satisfie

(See Re

Subject 11's partner was absent, so he completed the second level by himself. He followed the instruction to experiment with whole length, half length and quarter length pendulums.

In his first experiment---using the whole length to make a simple pendulum, he made two mistakes. One was an observation mistake. He wrote down 8.500 instead of 8.050. Another error was a calculation mistake, 8.050-6.000=1.050 (the correct answer was 1.950). As a result, the time intervals between each two adjacent peaks were: 1.95 seconds, 2.50 seconds, 2.025 seconds and 1.050 seconds. If his two errors had been corrected, the periods would have become: 1.95 seconds, 2.05 seconds, 2.025 seconds and 1.950 seconds. (The conclusion in this experiment should have been: the time intervals between two adjacent peaks were approximately 2 seconds and were almost constant.) Due to his mistakes, Subject 11 did not draw a correct conclusion.

In his second experiment---the half length simple pendulum and in his third experiment---the quarter length simple pendulum, he did not make any observation or calculation errors. He concluded correctly that the time intervals between the two adjacent peaks were almost constant.

From his third experiment, he concluded that pendulum clocks were not as accurate as a digital watch because their periods were not exactly the same.

Subject 13 & Subject 14 (level two experiment)

Subjects 13 & 14 measured their periods by finding the time intervals between two adjacent troughs. (Figure 4-8 provides more details.) These two students only measured the period of each pendulum and the mass-spring oscillation. They did not make mistakes and did not explore additional alternatives. They were apparently satisfied with their results. Their experimental results are presented in Table 4-7 (See Research question two).

Subject 19 & Subject 20 (level two experiment)

They worked together. One person moved the arrow and read the time from the screen and the other person wrote down the time and calculated the period. Their performance was similar to the two former subjects. Their experimental results are presented in Table 4-7.

Subjects 21, 22 and 23 had prior experiences in adjusting a pendulum clock. Subjects 21 and 22, who had learned about the simple pendulum theory in college, were more interested in pursuing the analytic capabilities of the PSL. Subject 21 will be discussed under research question three, Subject 22 will be discussed under research question four and Subject 23 will be discussed under research question nine.

Discussion of the Simple Pendulum Experiment

All of the subjects used similar methods to measure the period of the Simple Pendulum (i.e. by finding the time intervals between two adjacent peaks). The PSL graphs showed the relationship between time and displacement of the oscillation very clearly. This understandable computer display seemed to assist the subjects to generalize their ideas in measuring the periods. Subjects 1, 3, 4, 11, 19 and 20 measured the periods by finding the corresponding time of two adjacent peaks. Subjects 13 and 14 measured the periods by finding the corresponding time of two adjacent troughs. In addition, Subjects 3 & 4 discovered that the data in the Data Table were also a good way to find the periods. The Graph command and the arrow key provided a powerful tool for the subjects to measure the periods exactly. As mentioned earlier, Subjects 3 & 4 found that the periods they measured by using the arrow tool and the periods they measured by using the Data Table matched very well. These perfect matches were not coincident. The arrow tool read the exact data points that produced the graph. However, this capability does not guarantee that a subject is able to locate the peak point. As this researcher observed how Subjects 3 & 4 measured the corresponding time of eac

of th

rela

were

If th

the s

gave

at th

same

that e

deta

were

expan

the sh

becam

middle

were a

higher

signifie

find th

shorter

knowle

more h

high sch

each peak, they moved the arrow tool back and forth until they obtained the highest value of the distance. This measurement suggested that Subjects 3 & 4 understood the relationship between the peak and the distance.

After the experiments, subjects were given a picture of a pendulum clock and were asked three questions: 1) Why can a simple pendulum be used to make a clock? 2) If the clock goes fast in the Winter, how do you adjust it? 3) If the clock goes slowly in the Summer, how do you adjust it?

All subjects no matter whether they were high school or middle school students gave accurate answers to these three questions. In answering question one, a casual look at the computer graphs showed that each swing of a simple pendulum took almost the same time. Their subsequent measurements by using the graph's analysis tool proved that each subject's prediction was accurate. (Figure 4-6 and Table 4-6 provides more details) In answering question two and question three, the three high school subjects were able to make a correlation between their experimental results and the heat expansion. Their experimental results was that the shorter the length of the pendulum, the shorter the period. The heat expansion in this situation was that a pendulum's length became shorter when the temperature decreased and vice versa. The five subjects of the middle school were able to make a connection between period and temperature when they were asked "Will the pendulum become longer or shorter when the temperature is higher?" They answered question two and three correctly. The subjects' answers signified that both subjects who were from high school and middle school were able to find the relationship between pendulum length and period--the shorter the length, the shorter the period. However, their abilities to link the experimental findings to prior knowledge like heat expansion differed. Middle school students showed that they needed more help from teachers than did the high school students.

From the observation of the Simple Pendulum experiment, this author found that high school and middle school students used similar procedures to analyze their exp

abo

able

per

prog

mic

cond

the

does

how

dem

in th

Wint

Sum
and t

simple

the si

used

pendu

tempe

both th

subjec

what th

formula

experimental data. They reached the same conclusions and were able to answer questions about the pendulum clock correctly. This suggests that the middle school students were able to learn the simple pendulum concept such as, period and the relationship between pendulum length and the period, if appropriate learning materials (e.g. the PSL program) were available to them. It should be noted that none of the subjects from the middle school and only one subject from the high school had learned the simple pendulum concept prior to the PSL experiments. The subjects from the middle school did not know the terminology, "period". Therefore, the researcher had to ask the question "how long does it take for each swing" instead of using the word "periodic." In their answers on how to adjust a pendulum clock in the Summer or in the Winter, all the subjects demonstrated that they were able to adjust a pendulum clock: i.e. screw the pendulum up in the Summer (which shortens the pendulum) and screw the pendulum down in the Winter (which makes the pendulum longer).

Summary of the Simple Temperature Experiment and the Simple Pendulum Experiment

The temperature and pendulum clock problems are "real-world" problems. The simple temperature experiment provided a conflict for the subjects' reasoning. Through the simple pendulum experiment, the subjects understood why a pendulum clock could be used to regulate the time of a clock and provided appropriate solutions to adjusting the pendulum clock when it moved too slowly or quickly.

These two experiments involved two types of learning processes. The temperature experiment was simple, but the phenomena was not simple. It challenged both the subjects who had physics background and those who did not. About 30% of the subjects who had no physics background asked, "Why was there a difference between what they felt and what they observed?" Two subjects who had physics background formulated two assumptions to explain this dilemma. According to Thornton (Thornton, 1987), additional interaction is needed and further guidance may be necessary in order to complete this learning process. In the simple pendulum experiment, the computer display and measuring tool that the PSL provided help students to discover the time interval of each swing. The ability to repeat experiments with different pendulum lengths helped students find the relationship between the length and the resulting period. Consequently, students were able to answer the three questions about the pendulum clock correctly. This experiment appeared to be a good learning process. However, the subjects' abilities to make a connection between experimental results and prior knowledge differed from the high school to the middle school.

Level Three

Only Subject 21 and Subject 22 participated in this level. Their performances will be discussed under research question three and research question four.

Finding 1: With the help of the PSL and some appropriate printed and video materials (e.g. Appendix A & D), the subjects in this study, ranging from middle school students to graduate college level students, were able to explore some "real world" problems and learn physics concepts from real-time experiments. The simple temperature experiment created a challenging phenomena for subjects. Some subjects who had no physics background asked why this challenging phenomena happened. Some subjects who had physics background formulated two assumptions to explain it. The simple pendulum experiment helped subjects to discover the time interval of each swing and the relationship between the period and the pendulum length.

Research Foci Two: What Computer Skills Do Subjects Gain for Future Research from the PSL?

> To make laboratories engaging and effective for developing useful scientific intuition, students need powerful, easy to use, scientific tools with which to collect physical data and to display them in a manner that can be manipulated, thought about and remembered. (Thornton, 1987)

All the examples in this section came from level two observations. In level two experiments, subjects chose the probes that they wanted and designed their own experiments. Their exploration and understanding of the experimental results differed. The following examples show how the PSL allowed subjects to manipulate and analyze the data. These practices helped subjects use the PSL to do research in a way that is similar to the practices of professional scientists.

Subject 3 & Subject 4 (level two experiment)

The previous section emphasized what subject-matter knowledge that subjects learned. Subject 3 and Subject 4's performance in the simple pendulum experiment also demonstrated how they took advantage of different PSL tools to investigate the period of a simple pendulum. The following analysis focuses on their use of the research tool.

They began by using the PSL to collect data and found that the period of the pendulum was 2.10 seconds. (Note: This was their first trial.)

Following this first trial, they ran the PSL again to collect another set of data to see whether the pendulum kept the same period after a short time. They found the period of the pendulum was 2.00 seconds. (Note: This was their second trial.)

When they compared these two results, Subject 4 formulated a hypothesis, "While the pendulum was swinging, the amplitude was reducing, so the pendulum moved faster and faster." (Note: This was subject's first hypothesis.)

To test Subject 4's hypothesis, the experiment was run one more time. They found that the period of the pendulum was 2.025 seconds. Since 2.025 seconds was greater than 2.00 seconds, Subject 4 discovered that her first hypothesis, "If the amplitude was reduced, the pendulum would move faster," was not accurate. Subject 4 formulated another hypothesis, "We couldn't find the exact points of the peak deflections from the graphs." (Note: The subject formulated a new hypothesis)

To find an accurate way to figure out the period, Subject 3 explored the computer's top menu. As Subject 3 opened the Table from the top menu, a window displayed the pop-up data of Time, Distance and Velocity. Subject 4 discovered a new way to measure the period using the Data Table. The subjects then used the data from the computer's Table to verify whether they had measured accurately while using the computer graphs. The results showed that the periods they measured from the computer graphs and the periods they obtained from the Table matched exactly. This meant that Subject 4's second hypothesis was incorrect. (Note: Second Test)

After testing their hypotheses twice, the subjects tried to find other hypotheses to test using the PSL. They could think of no new ideas for further testing at that time.

The total time they spent on this investigation was about 30 minutes.

The research procedure that Subject 3 and Subject 4 applied in the simple pendulum experiment was not new for high school students, especially for those who had taken science classes in high school. The questions raised in this example were:

• Would Subject 4 be able to detect the differences among 2.10, 2.00 and 2.025 seconds without the help of the PSLs measuring tools? Subject 4 recalled that when she performed the simple pendulum experiment in her physics class, she counted 1, 2 ....16 and divided the total time by 16 in order to find the period. The stop watch and the counting method that Subject 4 used in her physics class did not provide an opportunity for her to measure the period accurately. The PSL program provided this capability.

• Could Subject 4 formulate the two hypotheses without the help of the PSL at that time? Subject 4's two hypotheses were achieved based on the accurate measurement of the time intervals of two adjacent peaks. It was impossible for Subject 4 to find the difference between the time intervals by using the stop watch she had in her physics class.

• Could Subject 3 and Subject 4 complete three trials and two tests in 30 minutes without the help of the PSL at that time? Upon completing the experiments, Subject 3 said: "It (the PSL) is faster." and Subject 4 said, "You don't have to write it down." Their responses suggested that the PSL helped them save time in collecting and analyzing data, so that they could complete three trials in a short time.

Discussion:

Subject 3 and Subject 4 were high school students. Subject 3 had taken introductory analysis and Subject 4 was taking physics at that time. Subject 4 remembered when she measured the period of a simple pendulum in her physics class, she counted it 1, 2, 3 ...... 16 and then divided the time by 16. This was the only thing she explored in her regular physics class. This time, she used the PSL to explore the simple pendulum in greater depth than she had in her physics class. Since the motion probe was very sensitive (six significant digits), the data she and Subject 3 collected showed differences among the periods after two trials. She formulated two hypotheses and tested them. Her approach was: Try---try again---formulate a hypothesis---test the hypothesis---formulate a new hypothesis, and then test the new hypothesis again, the same approach used by professional scientists.

It was interesting that these two subjects were stimulated by the notion of research and wanted to test additional hypotheses. The differences between these two subjects and the other grade school subjects were that Subject 3 was the only high school subject who took Introductory Analysis and Subject 4 was the only high school subject who took physics.

Subjects 1, 3, 4, 11, 13, 14, 19, 20 (level two experiment)

It was interesting to observe that all subjects used similar ways to determine the periods. The procedure they used to determine the period was to: 1) use the PSL to collect the data, 2) move the arrow to find the corresponding time of each peak, 3) calculate the time intervals between the two adjacent peaks(or troughs), and 4) make an approximation for the periods. As mentioned in the previous section, all subjects in the pendulum experiment were provided instructions on how to get a correct pendulum graph. This provision was based on the fact that this researcher asked five people who were not subjects in this study to try the PSL program. These five people had difficulty in obtaining a correct pendulum graph. With the help of given instruction, none of the subjects in the pendulum experiment had trouble in obtaining a correct pendulum graph. As a result, the instructor gave the subjects the needed direction in order to perform the pendulum experiment. The interested result was not that their general directions were similar. The interesting result was that their specific procedures in accomplishing their tasks were similar. For examples:

• In order to use the PSL to collect data, some subjects selected the Distance & Velocity set-up, some subjects chose Distance vs. Time set-up, some subjects created their own experiment set-ups to meet their needs. No one selected Temperature vs. Time or other experiment set-ups to collect the data in the pendulum experiment. It appeared that all subjects in performing the pendulum experiment were able to apply the knowledge they had learned in level one. They were able to select or created an appropriate experiment set-up to collect data.

• When subjects performed the pendulum experiment, everyone demonstrated that they were able to apply the arrow tool to find the corresponding time of each peaks. All subjects practiced using the arrow tool to find the values of points on a graph (see Appendix D). Their performance in the pendulum experiment showed that they were able to apply this data analysis tool to a new situation.

• Subjects who performed the pendulum experiment to calculate the time intervals between two adjacent peaks (or troughs) demonstrated that they understood that one sine wave on the computer screen represented one swing of the pendulum. Their similar performances implied that subjects doing the pendulum experiment were able to apply the available tools that they had learned in the first level to a new experiment.

By using the PSL to find the period of a pendulum, Subject 19 and Subject 20's approach was typical:

In the first experiment, whole length pendulum, they used the PSL to collect data and record the data as follows:

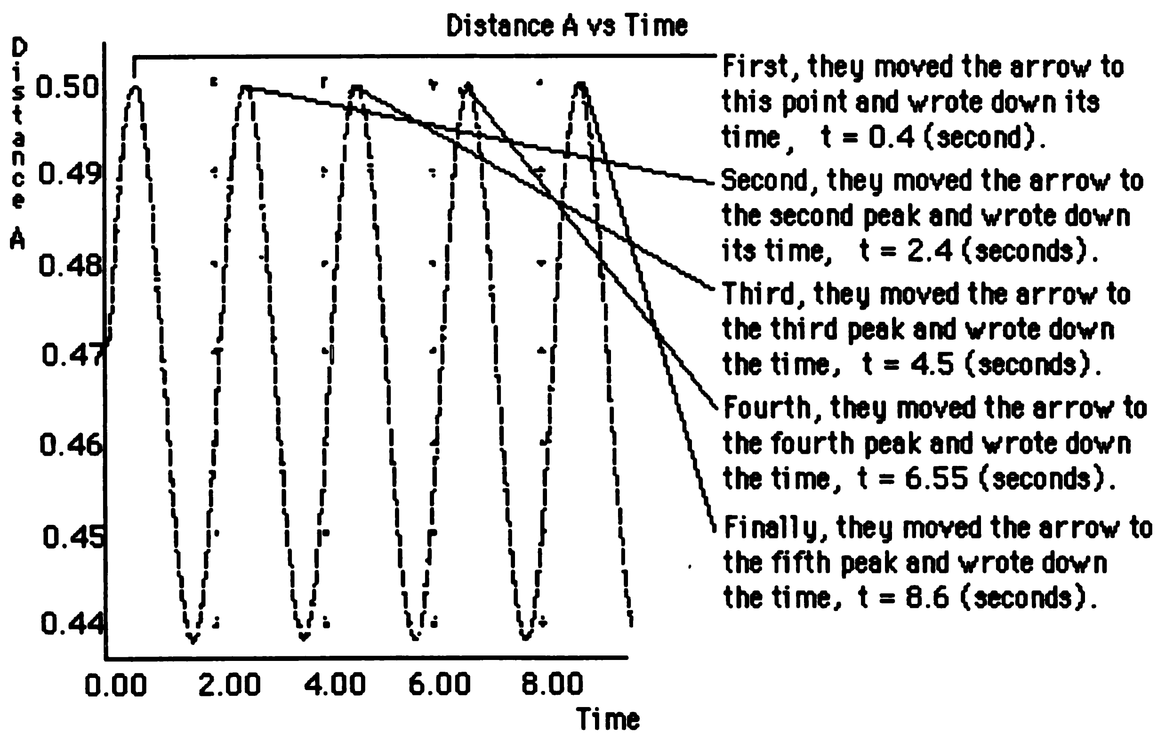
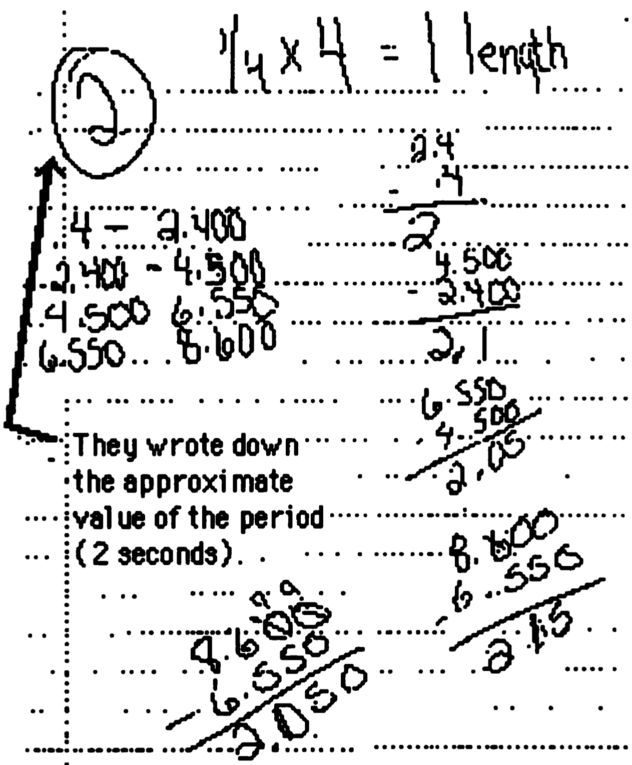


Figure 4-6 Subject 19 & Subject 20's Whole length simple pendulum data

Based on the Figure 4-6 data, they calculated each time interval between two adjacent peaks. Finally, they made an approximation and determined the period of this pendulum. The period was approximately two seconds.

Original



Translation

1/4*4 = 1 lengh

```
   2.4
 -  .4
 -----
   2
```

.4 - 2.400
2.400 - 4.500
4.500 - 6.550
6.550 - 8.600

```
  4.500
- 2.400
-------
  2.1

  6.550
- 4.500
-------
  2.05

  8.600
- 6.550
-------
  2.05

  8.600
- 6.550
-------
  2.050
```

Figure 4-7 Subject 19 & Subject 20's whole length simple pendulum calculation

Subject 13 and Subject 14 measured the periods by finding the time intervals between two adjacent troughs.

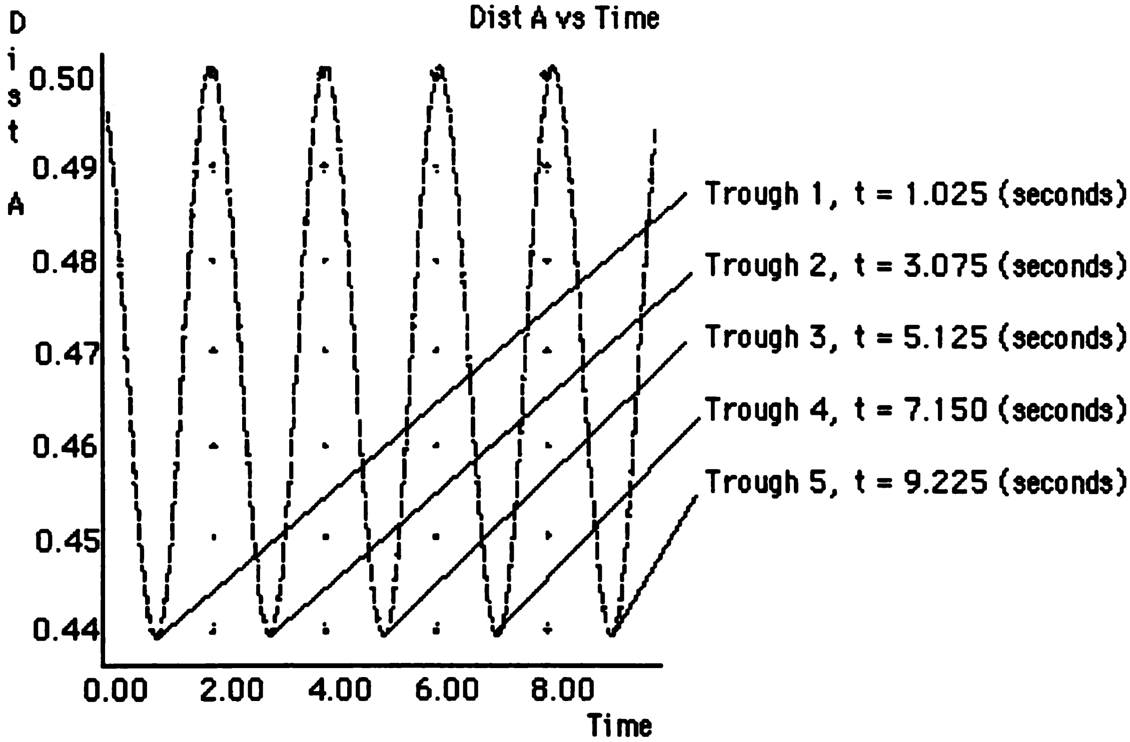


Figure 4-8 Subject 13 & Subject 14's Long String simple pendulum data

Based on the above data, they calculated each time interval between two adjacent troughs.

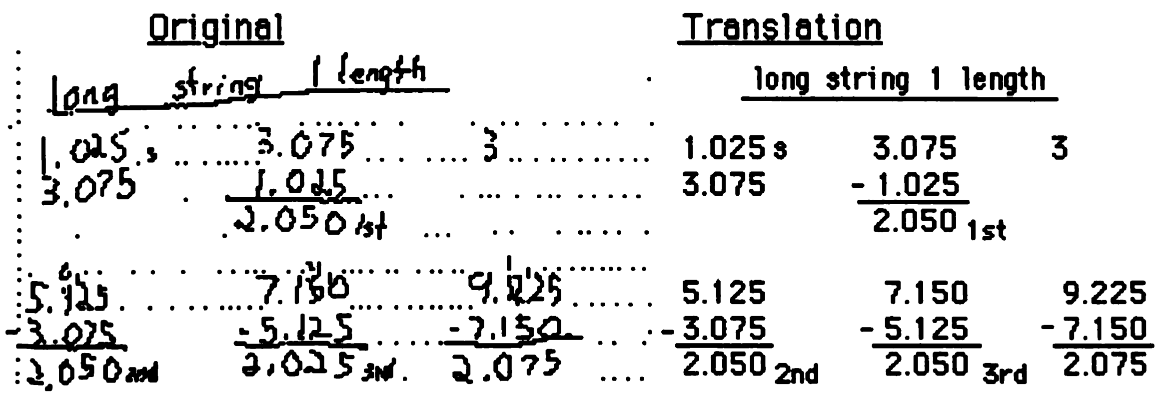


Figure 4-9 Subject 13 & Subject 14's Long String simple pendulum calculation

Table 4-7 summarizes the subjects' experiment results and their procedure.

Table 4-7 Summary of the experiments of the Simple Harmonic Motion

<table>
<tr><th>Subject (Year in sch.)</th><th>Period of a whole length simple pendulum (in seconds)</th><th>Period of a 1/2 length simple pendulum (in seconds)</th><th>Period of a 1/4 length simple pendulum (in seconds)</th><th>Period of a Mass-Spring Oscillation (in seconds)</th><th>Method and procedure used to find the period</th></tr>
<tr><td>Subject 1 (11th grade)</td><td>(not done)</td><td>1.27</td><td>0.99</td><td>1.2</td><td rowspan="5">(All the same) Method--by measuring the time interval between two adjacent peaks.
Procedure:
Collecting
↓
Measuring
↓
Recording
↓
Calculating</td></tr>
<tr><td>Subject 3 & Subject 4 (11th grade)</td><td>2.04</td><td>(not done)</td><td>0.875</td><td>1.2</td></tr>
<tr><td>Subject19& Subject20 (8th grade)</td><td>2.00</td><td>1.40</td><td>1.00</td><td>1.2</td></tr>
<tr><td>Subject13& Subject14 (7th grade)</td><td>2.05</td><td>1.45</td><td>1.075</td><td>1.2</td></tr>
<tr><td>Subject 11 (7th grade)</td><td>2.025</td><td>1.425</td><td>1.05</td><td>1.2</td></tr>
<tr><td>Subject 21 (Graduate Student)</td><td colspan="5">Did not complete measurement.</td></tr>
<tr><td>Subject 22 (Graduate Student)</td><td colspan="5">Did not complete measurement.</td></tr>
<tr><td>Subject 23 (Teacher)</td><td colspan="5">Did not complete measurement.</td></tr>
</table>

Subject 2 did not perform the simple harmonic motion experiment. He chose the pH probe to measure the pH value of water. His approach will be discussed under research question eight.

After Subject 21 collected data from the experiments of simple harmonic motion, he tried the arrow keys on the computer to find the corresponding time of each peak or trough. He then concentrated on finding equations to represent the data he had obtained.

He did not complete the measurement for this experiment. (Further detail is presented in research question three.)

Subject 22 also tried the computer's arrow keys to find the corresponding time of each peak or trough. Then he explored the calculation commands that the PSL provided in order to perform some complex calculation. He did not complete the measurements. (Further detail is presented in research question four)

Subject 23 participated in level two for only 30 minutes. He explored the usage of the computer's F4 key (scale graphs) after he collected the data. He did not completed the measurements. (Further detail is presented in research question ten)

Discussion:

Subjects from middle school and high school used procedures similar to those professional scientists use, that is: collecting--measuring--recording--calculating. In other words, the experiences they obtained from the above experiments were authentic computer research skills.

Subject 11 (level two experiment)

Subject 11's exploration and explanation for the fit-line equation in the PSL program is illustrated in Figure 4-10 to Figure 4-12 .

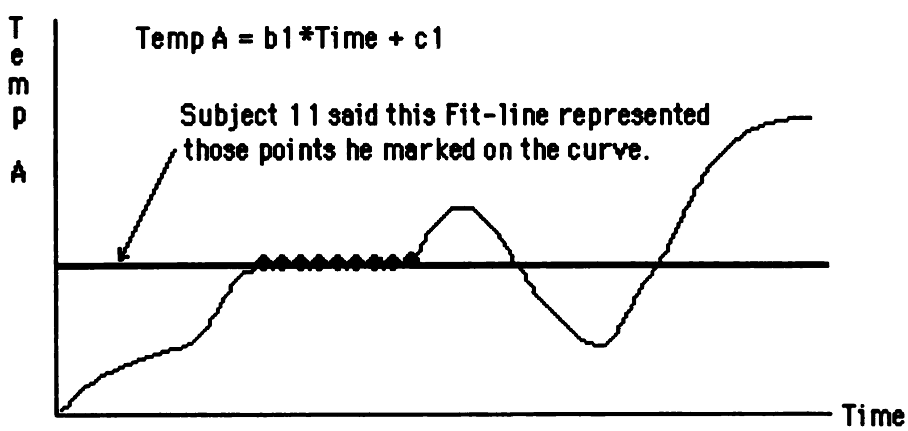


Figure 4-10 Subject 11's Fit-line Equation-1

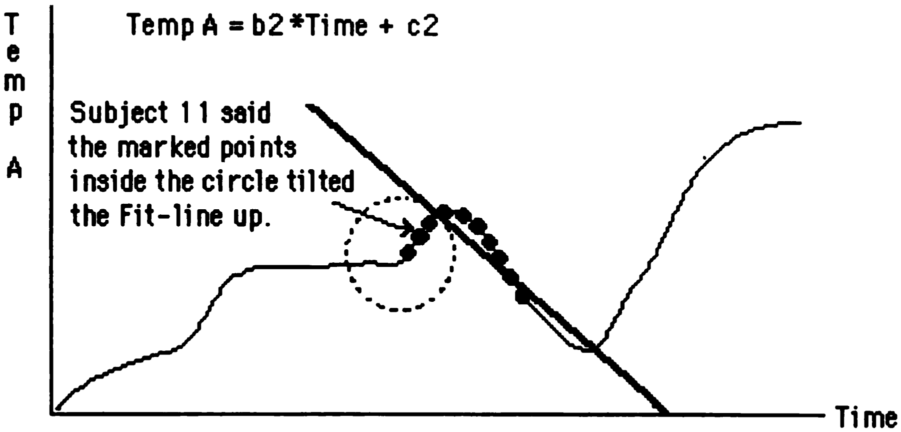


Figure 4-11 Subject 11's Fit-line Equation-2

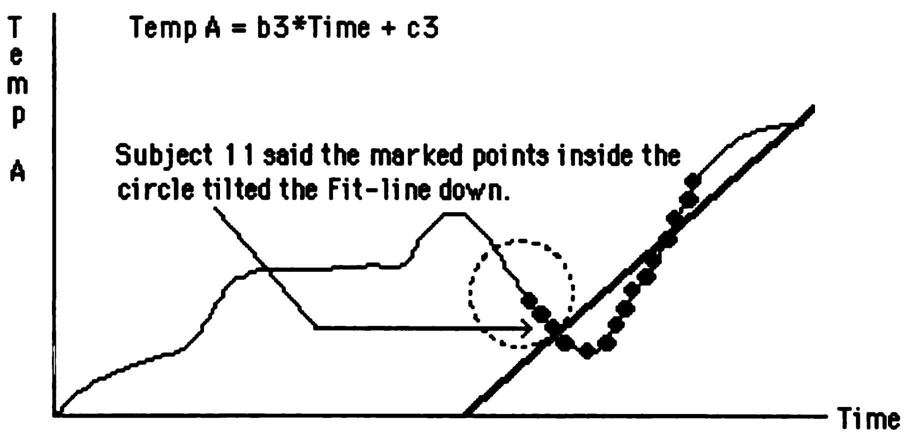


Figure 4-12 Subject 11's Fit-line Equation-3

The Fit-line and its equation raised Subject 11's curiosity. It was a useful tool for research, but it was beyond the capability of most of the subjects. Subject 11 explored and explained it as follows:

He said the first Fit-line represented the points he marked, the second and the third Fit-lines did not represent the points he marked because some points changed their directions.

From his exploration and explanation, it seemed that he had expected to find an equation to represent the points he had marked. The first Fit-line equation matched his expectation. He said the first Fit-line represented the points he marked. To further explore the relationship between the marked points and the Fit-line, he marked other parts of the curve and obtained two other Fit-lines. Each time that he marked new points and chose the Fit-line command, the computer gave him immediate feedback; he seemed to sense that some marked points affected the Fit-line directions. Even though the directions he pointed to in Figure 4-11 and Figure 4-12 were not accurate (i.e. tilted up or tilted down), this example showed that the PSL provided the kind of environment that encourages students to explore and find explanations with immediate feedback. Subject 11's interaction was only available in the computer environment. Exploring with the computer program, discovering its potential capabilities and trying to figure out why something happens in a certain way is a useful way to learn computer skills for future research. The theoretical bases of the Fit-line equation is probably too difficult for a middle school student to understand. However, the computer graphs and immediate feedback made a great deal of sense to Subject 11. If a teacher were present to guide him on how to use the Fit-line, he might have been able to use this research tool effectively.

Subject 11 also took advantage of the computer graphs to find his own calculation errors. In the Mass-Spring oscillation experiment, Subject 11 had two errors. He found the errors by comparing the wave on the computer screen with his own calculation results. Based on the results of his calculation, one of the time intervals was 1.350, which was much bigger than his other calculations. He wondered why this was so. By comparing the computer graphs with his calculation procedure, he found that he mistakenly wrote 2.150 instead of 2.325. He repeated the calculation. Unfortunately he had another calculation error this time (3.500 -2.325 = 1.275, the correct calculation should have been 3.500 -2.325 = 1.175). Subject 11's result was still inaccurate and only by chance was closer to the correct answer. This example showed that the comparison of the Mass-Spring wave on the computer screen and his calculation helped him find that the data did not fit very well; he looked at the data again for

solutions. When the results were closer to expectations (even though inaccurate), he was satisfied. The PSL provided Subject 11 with one more tool---computer graphs to examine his experimental results.

The following figures show how Subject 11 found his observation error and how he corrected it.

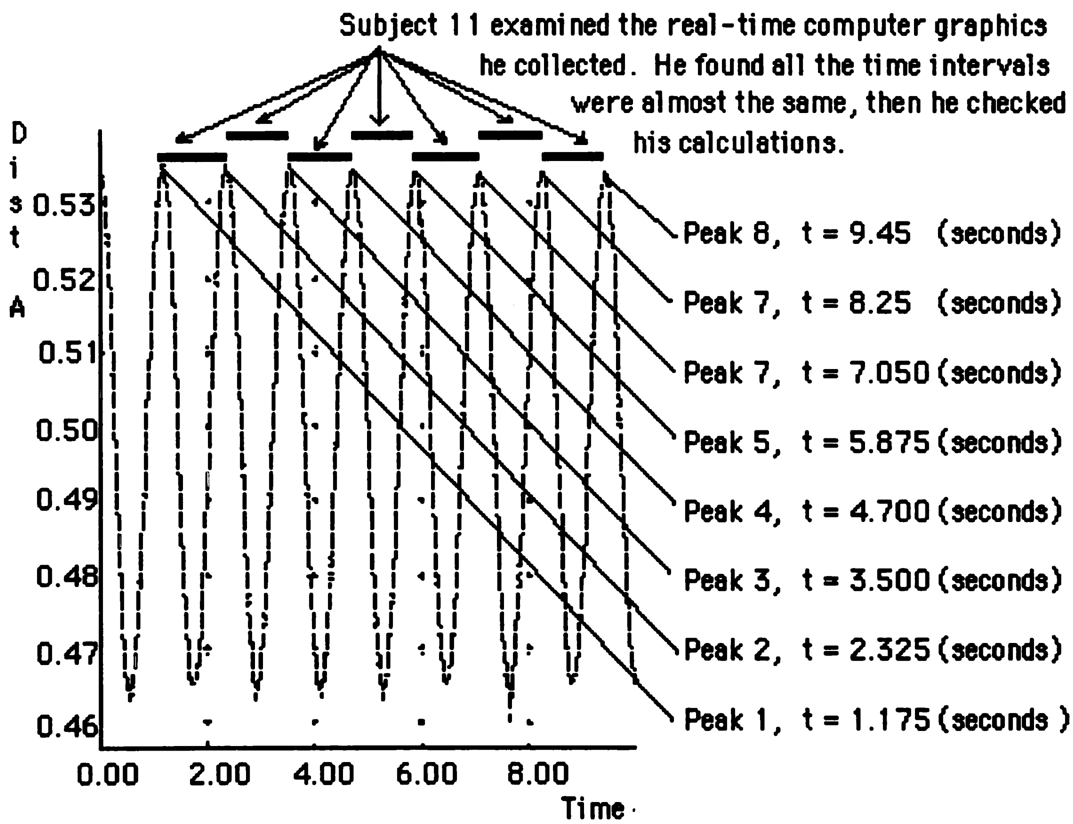


Figure 4-13 Subject 11's Mass & Spring Oscillation data

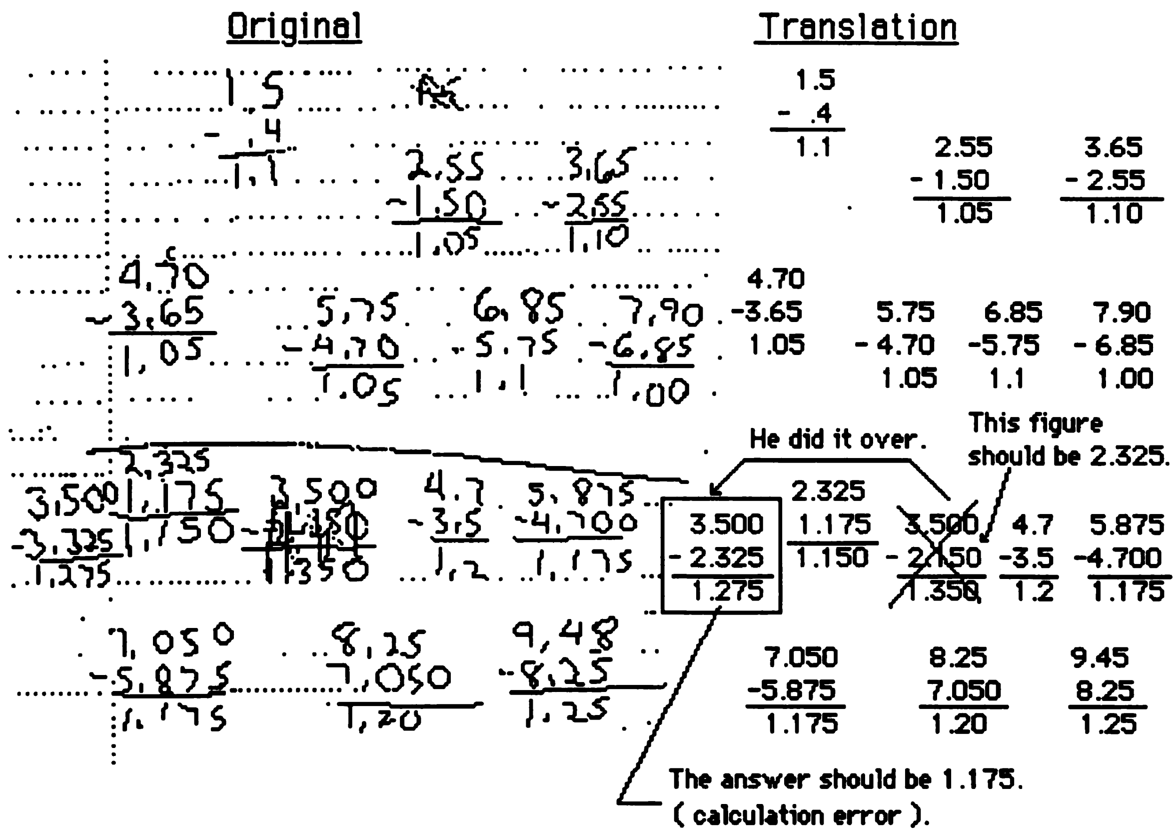


Figure 4-14 Subject 11's errors

In his Mass-Spring experiments, Subject 11 made two errors in the calculation process. One was that he copied a wrong number from the computer graphs. Another was a calculation errors. Later he found his errors by comparing his calculation results with that of the computer graphs. This capability of the PSL was useful for subjects because the computers stored the data and allowed subjects to examine the data again and again. Subjects could take advantage of the computer's unique characteristic--memory to obtain a correct experimental results.

In summary, the PSL allowed subjects to repeat an experiment immediately, do qualitative analysis (from the graph), quantitative analysis (by using the arrow and the table), and perform various kinds of calculations. The computer-based characteristics provided subjects with opportunities to quickly explore in depth the experimental data, test their hypotheses and discover their accuracy or error.

Finding 2: The PSL program enabled subjects to collect data quickly and analyze them immediately by using the analysis tools. These analysis tools included computer graphs, data tables and the arrow tool. They helped subjects measure the pendulum period accurately and analyze the experimental data very fast. During a short experimental period, subjects were able to spend a large portion of their time repeating their experiments. By repeating the experiments and analyzing their data with different tools that the PSL provided, some subjects formulated hypotheses and tested hypotheses again and again. Some subjects even found their errors with the help of these computer analysis tools. This procedure helped subjects experience the methods that how professional scientists use computers to do research.

<u>Research Foci Three: What approximation skills do subjects gain from the PSL?</u>

> Approximation skills. The student should understand when an equation is being treated approximately and the range of validity of all equations used. (Wilson, 1990)

In some situations, the data obtained in the experiments were not ideal. Researchers frequently compute approximations to find an equation which represents the data they obtain in order to better understand the phenomena.

In this study, only one person, who participated in the third level, was able to do approximations.

Subject 21 (level three experiment)

Subject 21 was a graduate student with a background in engineering and experience with computers. He was interested in doing approximations to find an equation to represent the data he collected from the PSL.

The first approximation he completed was the heating curve. He:

1) selected the One-Temperature experiment set-up and changed the Duration to 15 minutes (the temperature was displayed in Celsius degrees).
2) measured his body temperature by the temperature probe and exported the data to MS WORKS spreadsheet.

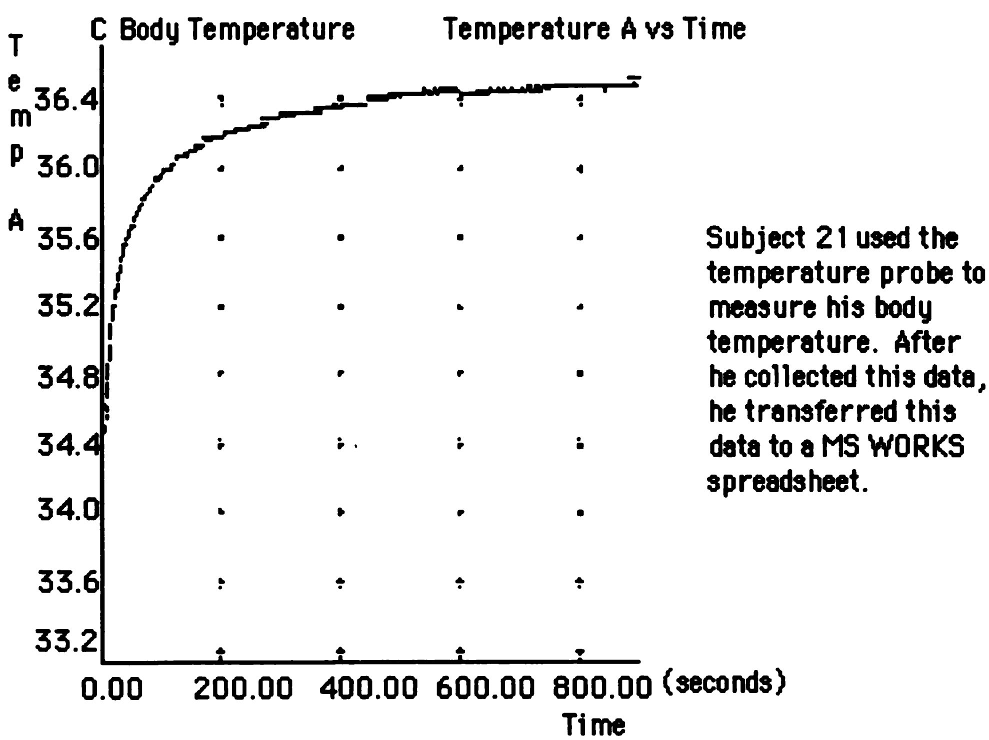


Figure 4-15 Subject 21's Body Temperature

3) added a column in the MS WORKS spreadsheet.

File Edit Print Select Format Options View

=LOG(A4)

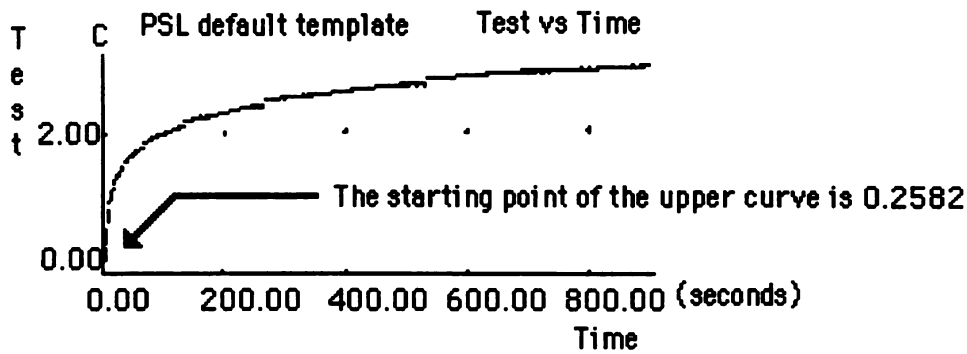
TEST.WKS

	A	B	C	D	E
2	s	c			
3	0.00000	33.28169			
4	1.81254	33.70299	0.258288		
5	3.62508	33.97560	0.559318		
6	5.43762	34.19864	0.7354092		
7	7.25017	34.42168	0.8603479		
8	9.06271	34.59515	0.957258		
9	10.87525	34.74385	1.0364392		
10	12.68779	34.81820	1.103386		
11	14.50033	34.91732	1.1613779		
12	16.31287	35.01645	1.2125305		
13	18.12542	35.06602	1.258288		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		

This new column was added and given the formula:
= LOG (A4)

Figure 4-16 A column with a formula =LOG(A4)

4) went back to the PSL , imported the spreadsheet (completed in step 3) to PSL and opened this new file. These new graphs were displayed:



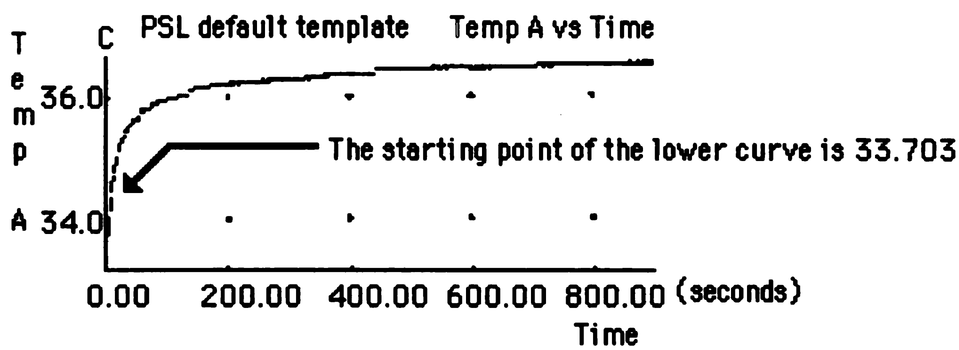


Figure 4-17 Graph of LOG(A4) vs. experimental graph

Comparing the upper curve and the lower curve, he found that the starting point was different (i.e. the initial value differed). He:

5) selected the upper graph and looked at the data from the table, he found that if 33.44 were added to the upper curve, then the upper and the lower graphs were almost the same.

6) used the computer's Calculate command to add 33.44 to the upper graph, then the two graphs became almost the same.

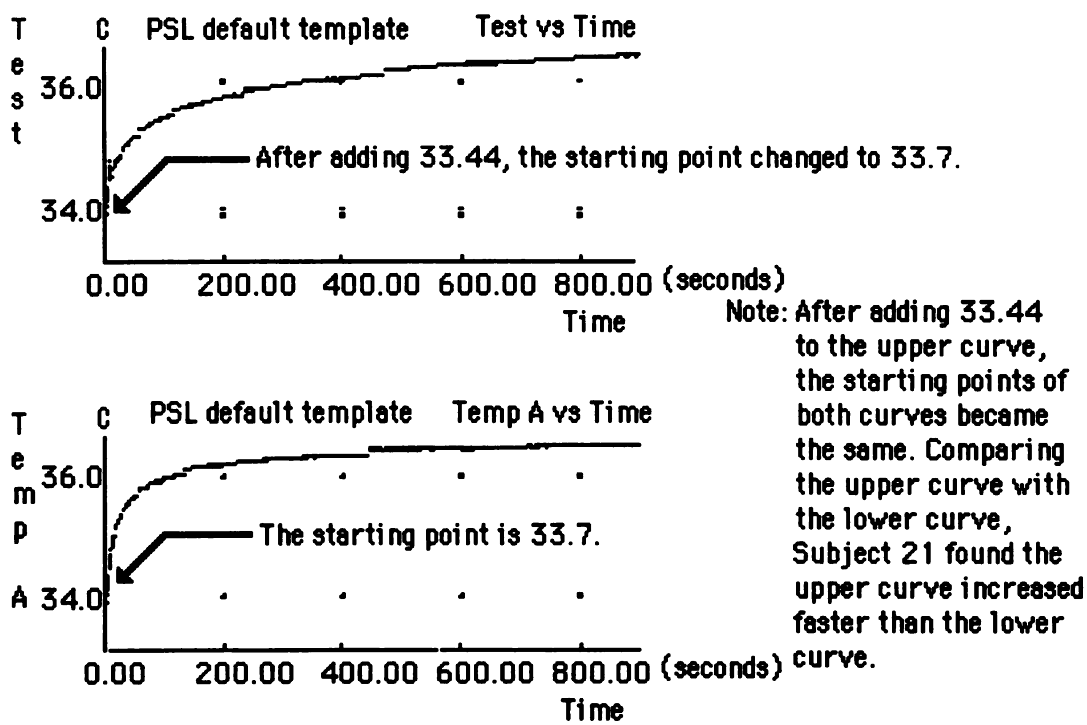


Figure 4-18 After adding 33.44

7) applied the formula **LOGbU = LOGaU/LOGab.** (Note: neither the PSL nor MS WORKS allowed him to use Logarithms with base other than 10 and *e*) He used this formula to keep the base as 10 in order to construct different approximation curves on MS WORKS and PSL. In order to find the best one to describe his data, he constructed the following graphs.

First he used MS WORKS to create a new column with a formula **=LOG(A4)/LOG(9)**.

=LOG(A4)/LOG(9)

LOG9X.WKS

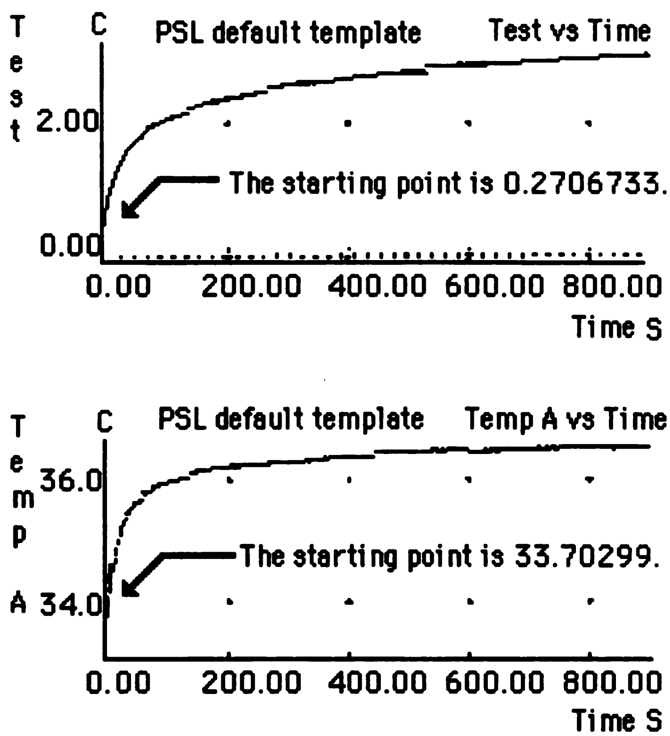
	A	B	C	D	E
2	B	C			
3	0.00000	33.28169			
4	1.81254	33.70299	0.2706733		
5	3.62508	33.97560	0.5861382		
6	5.43762	34.19864	0.7706733		
7	7.25017	34.42168	0.901603		
8	9.06271	34.59515	1.0031601		
9	10.87525	34.74385	1.0861382		
10	12.68779	34.81820	1.1562952		
11	14.50033	34.91732	1.2170679		
12	16.31287	35.01645	1.2706733		
13	18.12542	35.06602	1.3186249		
14	19.93796	35.14037	1.3620024		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		

He added a new column with the formula: =LOG(A4)/LOG(9)
Note: $LOG_9(A4)$ =LOG(A4)/LOG(9)

If the new column added 33.44 later, the value in the new column should become the same as the value in the middle column.

Figure 4-19 A column with a formula =LOG(A4)/LOG(9)

Then he exported the above file to PSL and displayed the curves.



The shape of both the upper and lower curves are almost the same now.

If the upper curve added 33.44, then the upper curve might represent the actual data (the lower curve).

This means that the possible theoretical approximate equation is:

$$\textbf{Temp} = \textbf{LOG}_9\textbf{(Temp)} + \textbf{33.44}$$

Figure 4-20 Graph of LOG(A4)/LOG(9) vs. experimental graph

Actually, he could use the same method to construct different curves with different bases (e.g., 8, 7, 11, 12) to find the best one to represent the "real-time" experimental data. It seemed this curve with base 9 represented the data well enough, so he stopped trying other bases.

When Subject 21 was asked about the theoretical foundation and the strategies that he used to perform this approximation, he said, "The heating curve looks like a logarithmic function when its base is greater than one. The PSL allows users to export the data to a spreadsheet program. It is then possible to create a function in the spreadsheet program that produces a curve which is close to the experimental data." He felt confident about the equation that he had found; he opened the Data Table from the top menu and showed the data to the researcher, "The experimental data and the approximation data were very close. Therefore, he concluded that the approximation data was accurate enough to represent the experimental data.

He also pointed out that if the base were less than 1, the shape of the curve would be faced up, and could be used to represent the cooling curves. Figure 4-21 shows the cooling curve that subject 21 obtained. To experiment with the cooling, he used a different approach. (For further information about the law of cooling, see Thomas Greenslade's article, "The Coffee and Cream Problem", The Physics Teacher, Vol. 32, March 1994) He:

1) selected the One-Temperature set-up, and changed the Duration to 5 minutes (the scale of temperature in the graph was Celsius, not Fahrenheit).
2) pulled out the extended temperature probe from the hot water and began collecting data.

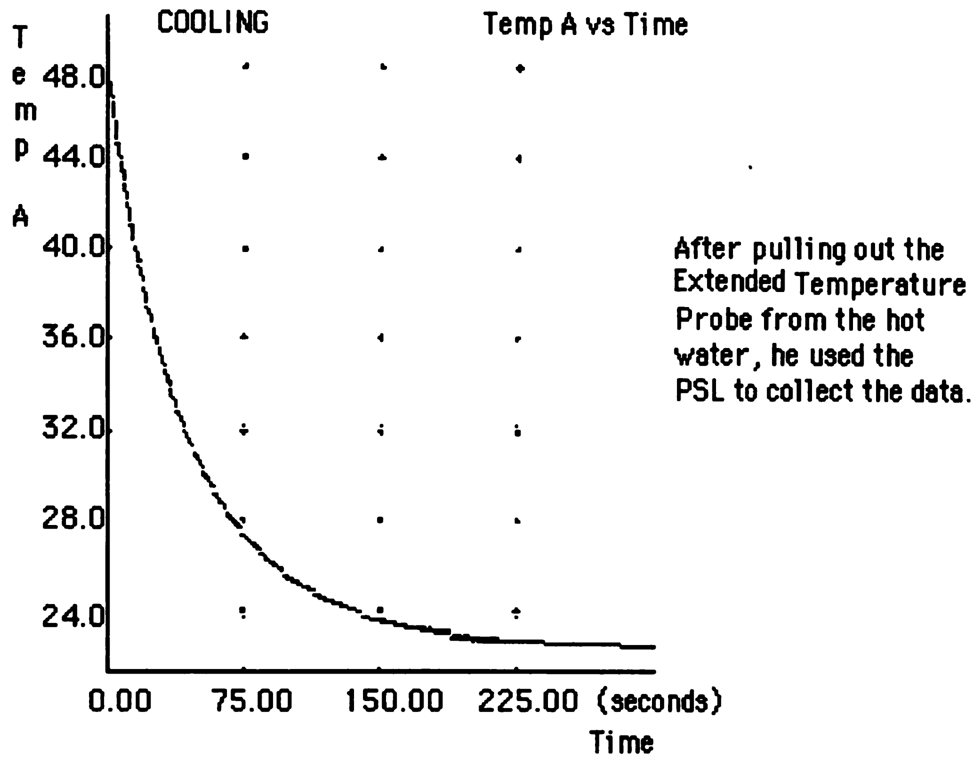


Figure 4-21 Cooling

3) chose LOG (base 10) from the Calculate menu, the cooling curve changed to:

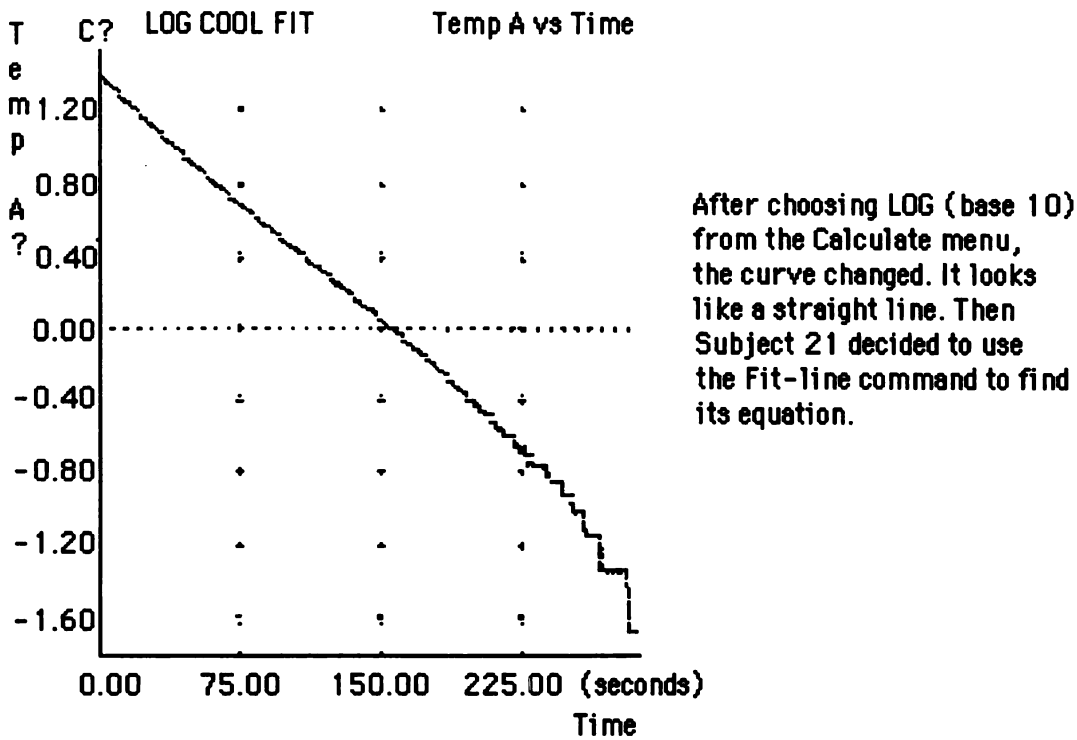


Figure 4-22 After applying LOG(base 10)

4) used the Fit-line command from the PSL to find the equation to represent the above graphs, then converted the Fit-line equation to the cooling equation.

Note: This approach was faster than the first approach.

The third approximation he completed involved a simple pendulum. He:

1) collected data from a simple pendulum by using the PSL.

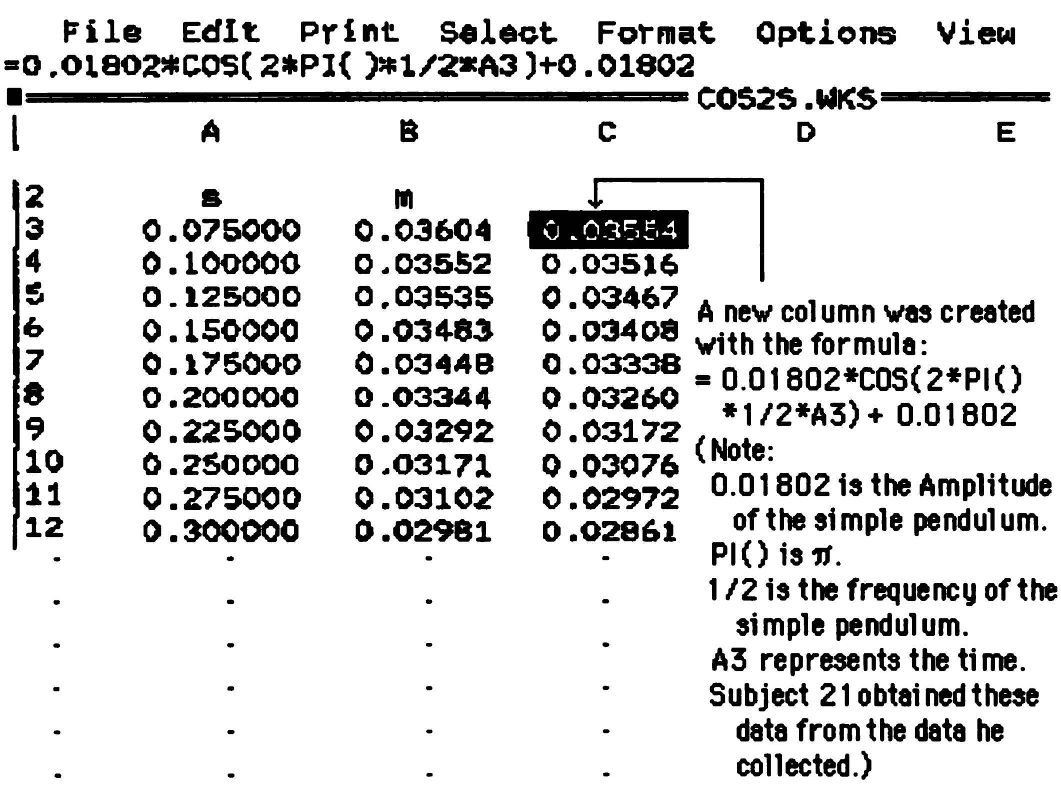
2) customized the shape of the wave to make the starting point either maximum or minimum by using the PSL, so as to more easily find a formula to fit it. (by deleting some of the point at the beginning).

3) exported the PSL data to MS WORKS.

4) opened this file from MS WORKS, deleted the columns of velocity and acceleration, and created a new column named cos2S.

5) input a formula:

=0.01802*cos(2*PI()*1/2*A3)+0.01802 (Note: PI() is π).

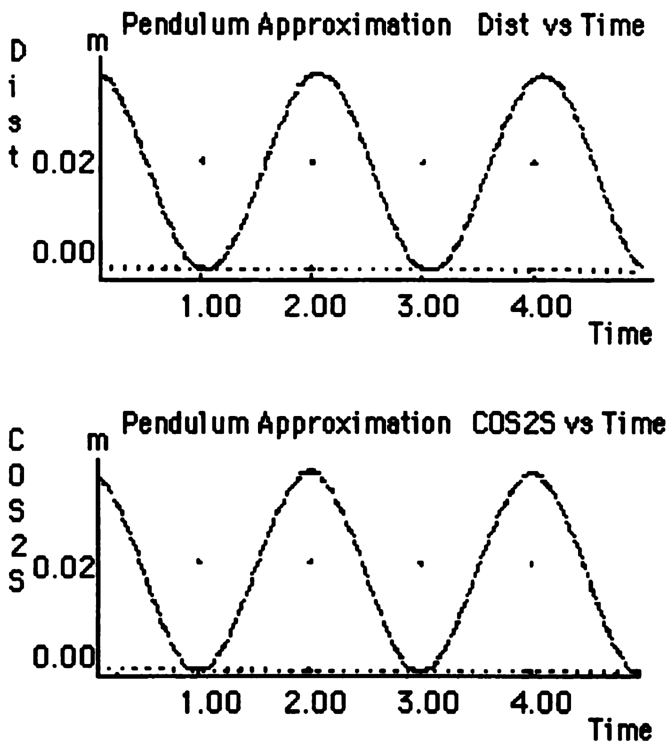


	A	B	C	D	E
2	s	m			
3	0.075000	0.03604	0.03554		
4	0.100000	0.03552	0.03516		
5	0.125000	0.03535	0.03467		
6	0.150000	0.03483	0.03408		
7	0.175000	0.03448	0.03338		
8	0.200000	0.03344	0.03260		
9	0.225000	0.03292	0.03172		
10	0.250000	0.03171	0.03076		
11	0.275000	0.03102	0.02972		
12	0.300000	0.02981	0.02861		
.	.	.	.		

Figure 4-23 A column with a formula

=0.01802*COS(2*PI()*1/2*A3)+0.01802

6) went back to PSL and opened the curves.



The uppper wave is the wave that Subject 21 collected by using the PSL.

The lower wave was created by using MS WORKS.

The theoretical approximation seems to coincide with the upper wave.

Figure 4-24 Pendulum Approximation

The two curves in Figure 4-24 show that the curve of COS2S vs. Time (an approximation) and the curve of the Distance vs. Time (real-time data) match.

The fourth approximation was used to determine the spring constant K from the PSL. From the curves of the Mass-Spring Oscillation, Subject 21 discovered how to use the PSL to solve the *spring constant* **K**. His strategies in completing this approximation are as follows:

> Based on Hooke's Law, the restoring force of a spring is directly proportional to the displacement: **F = - K X** (here **F** is the restoring force, **K** is the spring constant, **X** is the displacement). Applying Newton's

second law (i.e. **F** = **ma**, here **F** is the force, **m** is the mass, **a** is acceleration), the formulas are:

ma = - KX

m/K = - X/a

If **a** (acceleration) and **X** (displacement)are known, then **m/K** can be calculated.

Subject 21 used PSL to collect the data of Mass-Spring Oscillation as follows:

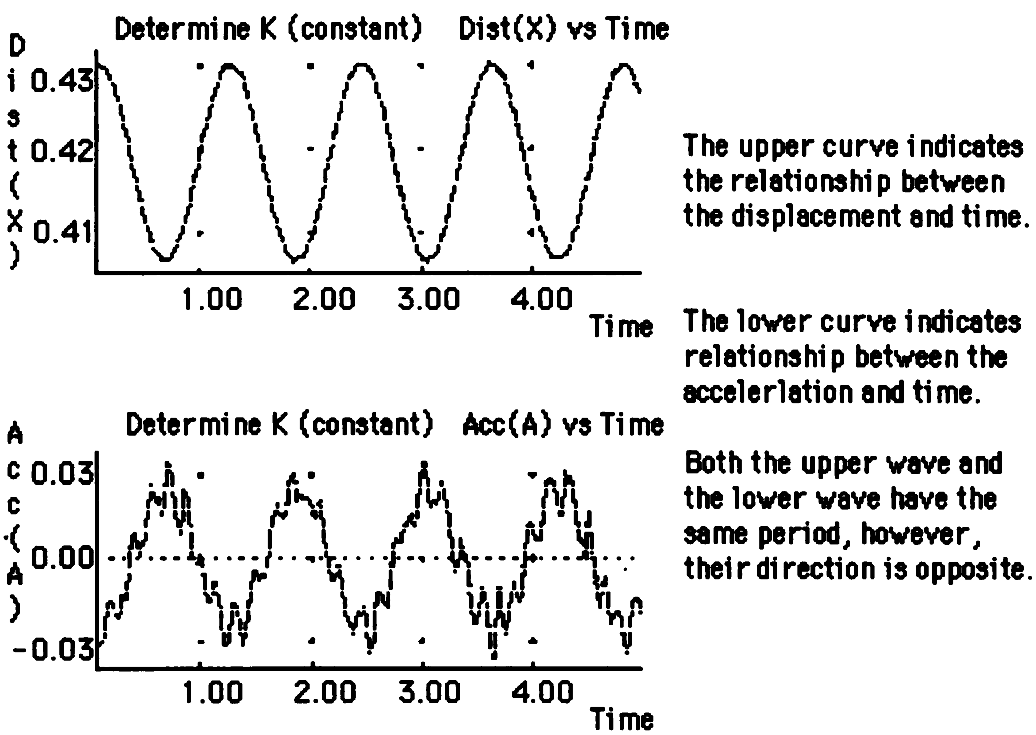
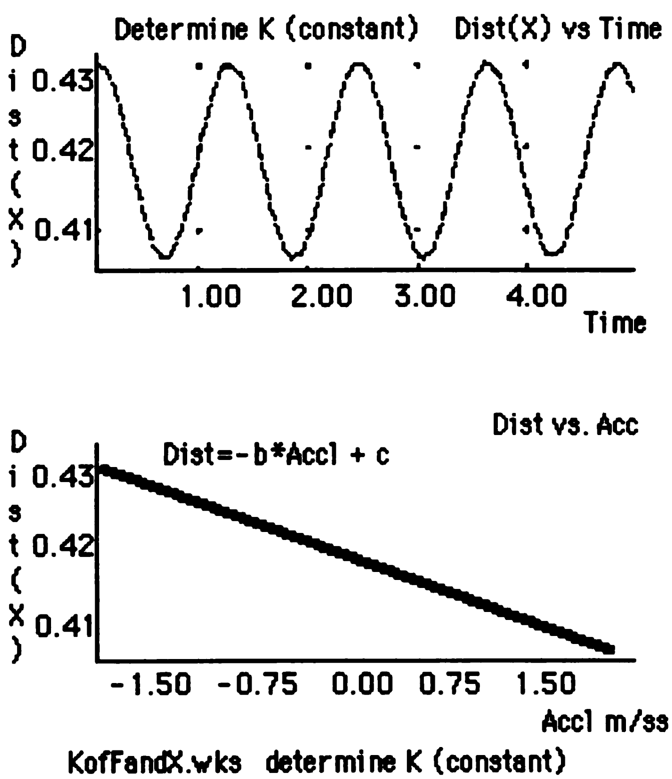


Figure 4-25 Determining K (constant)

After examining both the upper wave (Distance vs. Time) and the lower wave (Acceleration vs. Time), Subject 21 said he could use the above method to find equations to represent these two curves, and then found **m/K** by dividing these two equations. He tried this way several times, each time he got a different value of **m/K**. He could not find a satisfactory solution using this method.

He thought for a while and devised another approach, "If we create a graph displaying acceleration against distance, then we may find the **m/K** by simply using the Fit-line function to determine the Fit-line equation of acceleration against distance. The slope of the Fit-line equation of acceleration against distance will equal **m/K.**"

Following this new direction, the first important thing to do was to create a graph of acceleration vs. distance. He explored the **Reset Parameters** on the top menubar and produced the following graphs:



Subject 21 used the Reset Parameters on the top menubar to create a graph of Distance vs. Acceleration.
Then he used the Fit-line function to find the fit-line equation of Distance vs. Acceleration. The slope **-b** of the fit-line equation is equal to **m/k**.

Figure 4-26 Finding the spring constant K by using the Fit-line equation

When the subject was asked whether he felt confident about discovering the value of **m/K**, he replied, "The Fit-line equation is based on the Least-Square-Criterion, it is the best line to represent the data."

Discussion:

Subject 21, was a graduate student majoring in engineering who had a strong computer background. He stated that he had a difficult time trying to find an equation that represented the data that he obtained from these experiments while he was an undergraduate students; he was interested in approximation. In approximately three hours, he completed four theoretical approximations: 1) a heating curve (measuring the body temperature), 2) a cooling curve (a cooling temperature probe), 3) a simple pendulum wave and 4) a graph for determining a spring constant K. His approach in doing approximation was logical and had a very clear direction. His performance reflected his subject-matter knowledge and his computer experiences.

He used two methods to complete the above four approximations.

Method one: Combining the PSL and MS WORKS spreadsheet, he:

Step 1: created an appropriate experiment set-up and collected data by using the PSL, then saved this data.

Step 2: exported the data collected from the PSL to a MS WORKS spreadsheet.

Step 3: added a column in the MS WORKS spreadsheet with an appropriate formula.

Step 4: returned to PSL, imported the spreadsheet (completed in Step 3) to PSL and opened this new file to display the curves.

Step 5: compared the shape of the curve which represented the collected data with the shape of the curve which represented the formula added in Step 3. If their shapes were almost the same, he used the calculation function to adjust them so that they became the same. If their shapes were different, repeated Step 2 to Step 5 until both shapes were the same.

Step 6. combined the formula input in Step 3 and the calculation in Step 5 to write down the equation. This was the equation that represented the data collected from the "real-time" experiment.

Method two: Using PSL only, he:

Step 1: created an appropriate experiment set-up and collected data by using the PSL, then saved this data.

Step 2: analyzed the curve and found an appropriate calculation to change it into a straight line (or almost a straight line).

Step 3: marked this straight line (or almost a straight line), then used the Fit-line function to show its equation.

Step 4: combined the Fit-line equation that obtained in Step 3 and the calculation that used in Step 2 to write down the equation. This was the equation that represented the data collected from the real-time experiment.

Subject 21's case suggested that the PSLs environment allowed more knowledgeable users to experiment with multiple approaches to a solution. It provided a variety of tools in order to make it possible to accommodate different learners' prior knowledge and experiences. These tools supplemented each other. The tools that Subject 21 used in order to determine the spring constant k were good examples. Subject 21 exported the "real-time" experimental data to the MS WORKS spreadsheet and simply calculated the spring constant k by dividing the distance with the acceleration. The physical concept was very clear in this approach because it showed the direct relationships among the spring constant k, distance and acceleration. However, he could not find an appropriate solution using this approach. Finally, this lead him to explore and discover a better way--use the Fit-line tool, to find an accurate solution. In solving this problem, the capability of exporting data to a spreadsheet program provided Subject 21 a tool to calculate the spring constant K directly. However, the Fit-line tool provided him a more accurate way to find a solution. These tools provided an opportunity for Subject 21 to solve the same problem with various approaches.

Upon completion of these four approximations, Subject 21 said, "I could not imagine that I accomplished them so fast (in three hours)."

Finding 3: Approximation requires both strong computer experiences and subject-matter knowledge. In this study, two subjects participated in level three, but only one was able to do the approximations. The approximations that Subject 21 completed reflected his level of thinking. Subject 21's case suggested that the PSL did not teach him how to do approximations, but that the PSL environment assisted him in accomplishing the approximations faster and more accurately than was possible in a traditional physics laboratory. Subject 21's case also showed that the PSL helped him bridge the gap between theory and practice. For example, in order to determine the spring constant **K**, theoretically, he could find **m/K** by dividing acceleration by displacement. However, he did not get a satisfactory solution, since he obtained different values for **m/K** each time when he divided acceleration by displacement. His experimentation led him to discover that the Fit-line equation usage was more practical. If a teacher were present to provide stimulation and assistance, perhaps more students could have performed these approximations.

<u>Research Foci Four: Do subjects understand the calculation process when the PSL does all of the calculation?</u>

Data analysis involves numerous calculations. In traditional experiments, these calculations were very time consuming. In program-based experiments, students need to know programming in order to use computers to analyze data. The capability of using the calculation commands which the PSL provides is a needed innovation. A positive aspect of PSLs calculations, is the fact that the students do not have to spend hours learning computer programming. However, at level one, both subjects from high school and middle school did not explore the calculations that the PSL provided. In order to investigate how well subjects understood the calculation processes when the PSL performed them, those subjects from high school and middle school who performed the Mass-Spring experiment at level two were encouraged to try ADD, SUBTRACT, MULTIPLY and DIVIDE.

Table 4-8 summarizes the subjects' responses to ADD A CONSTANT and SUBTRACT A CONSTANT commands.

Table 4-8 Summary of responses to ADD & SUBTRACT:

Subject (Year in school)	Was able to explain changes in PSL graphics when applying ADD command to graphs?	Was able to explain changes in PSL graphics when applying SUBTRACT command to graphs?	Was able to explain changes in PSL Table when applying ADD command to graphs?	Was able to explain changes in PSL Table when applying SUBTRACT command to graphs?
Subject 1 (11)	Yes	Yes	Yes	Yes
Subject 3 & Subject 4 (11)	Yes Yes	Yes Yes	Yes Yes	Yes Yes
Subject19& Subject20 (8)	No No	Yes Yes	Yes Yes	Yes Yes
Subject13& Subject14 (7)	No No	Yes Yes	Yes Yes	Yes Yes
Subject 11 (7)	Yes	Yes	Yes	Yes
Subject 22 (Graduate student)	Yes	Yes	Yes	Yes

When they chose ADD A CONSTANT and entered a value of a constant (e.g., 2) from the Calculation menu, the Mass-Spring wave moved up 2, but the wave shape remained the same. Three subjects from high school and one subject from middle school found the changes on the Y axis and were able to explain them; four subjects from middle school could not identify the changes and therefore, could not explain them. After choosing SUBTRACT A CONSTANT and entering a value (e.g., 2), every subject noticed that the curves changed back to the original position. By repeating ADD A CONSTANT, then SUBTRACT A CONSTANT and comparing how the figures changed in the Table (a type of spreadsheets, where data were displayed), the subjects understood better how ADD A CONSTANT and SUBTRACT A CONSTANT worked. It appeared they recognized changes on the Table more quickly than on the graphs display. Perhaps, this was because the numbers changed in the Table, but the shape of the graphs did not change when a calculation command i.e. ADD A CONSTANT or SUBTRACT A CONSTANT, was applied.

Figure 4-27 and 4-28 illustrate the calculation process of Add A CONSTANT.

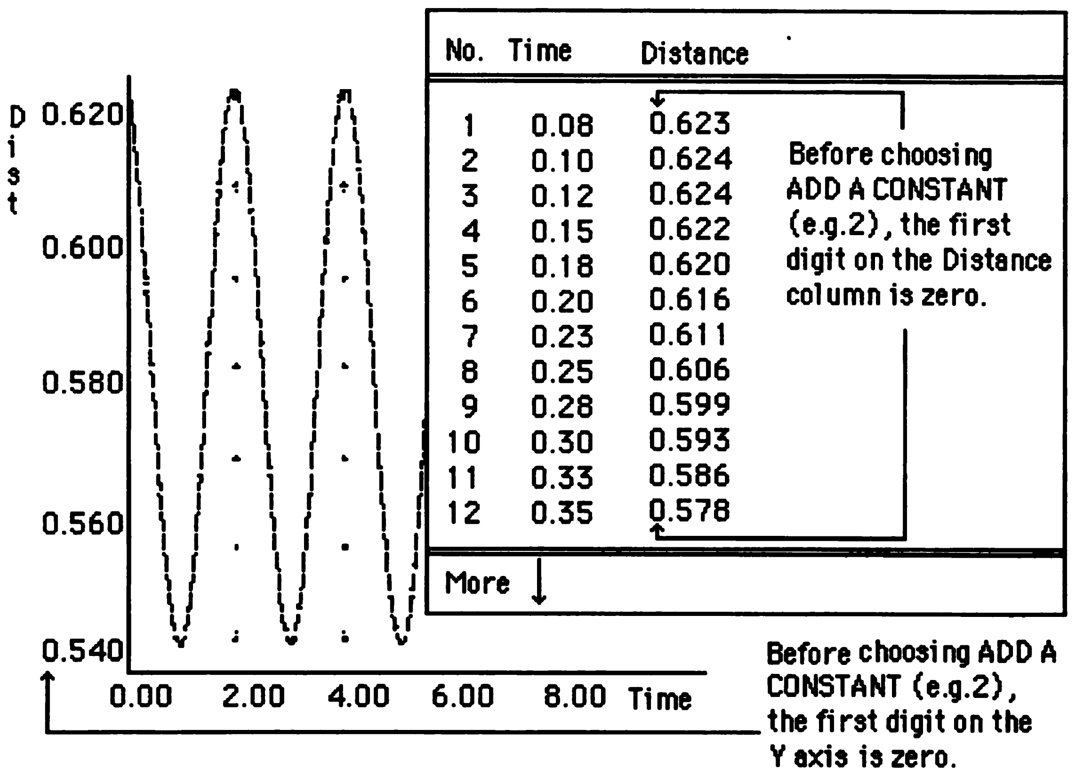


Figure 4-27 Before adding 2 to a graph

In Figure 4-27, all the first digits of numbers on the Y axis were zero and all the first digits of numbers in the Data Table were zero before subjects applied calculation commands. After they applied ADD A CONSTANT and entered 2 (i.e. added 2 to the distance), the graphs and the Data Table changed to Figure 4-28 (see next page). Notice that all the first digits in the Distance column of the Data Table and on the Y axis had been changed from zero to 2 simultaneously. However, the shape of the graphs was unchanged. Subjects noticed the changes on the data table more quickly than they noticed the changes on the labels of the Y axis, perhaps because the shape of the graph remained unchanged.

Figure 4-28 follows this explanation.

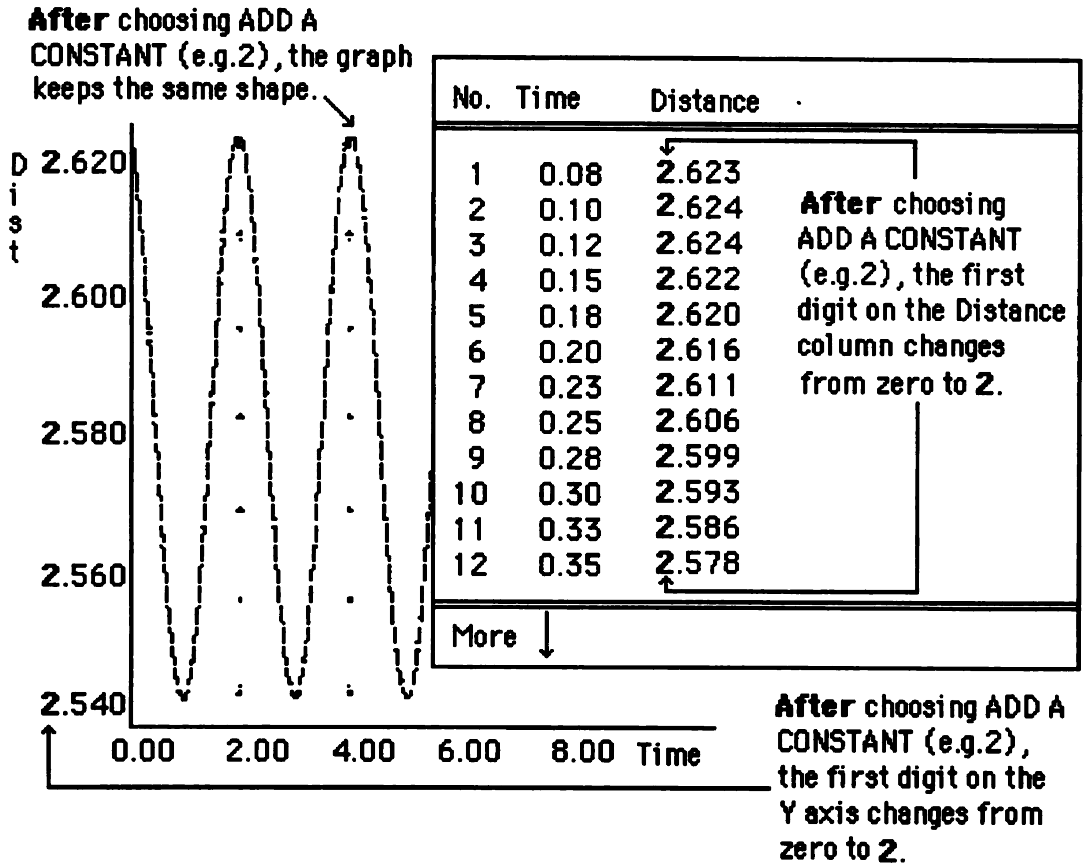


Figure 4-28 After adding 2 to the graph

Table 4-9 summarizes their responses to MULTIPLY and DIVIDE commands.

Table 4-9 Summary of responses to MULTIPLY & DIVIDE:

Subject (Year in school)	Was able to explain changes in PSL graphics when applying MULTIPLY command to graphs?	Was able to explain changes in PSL graphics when applying DIVIDE command to graphs?	Was able to explain changes in PSL Table when applying MULTIPLY command to graphs?	Was able to explain changes in PSL Table when applying DIVIDE command to graphs?
Subject 1 (11)	No	Yes	Yes	Yes
Subject 3 & Subject 4 (11)	No No	Yes Yes	Yes Yes	Yes Yes
Subject19& Subject20 (8)	No No	No No	Yes Yes	Yes Yes
Subject13& Subject14 (7)	No No	No No	No No	Yes Yes
Subject 11 (7)	No	No	Yes	Yes
Subject 22 (Graduate student)	Yes	Yes	Yes	Yes

The graphs resulting from applying the MULTIPLY BY CONSTANT command were more difficult for subjects to interpret. Even subjects from high school took quite some time to figure them out. When they chose the MULTIPLY BY CONSTANT command and entered a value (e.g. 2), both the shape of Mass-Spring wave and the numbers on the Y axis changed. The subjects found changes easily this time, but these changes did not make sense to them since the changes were different from the changes in ADD A CONSTANT and SUBTRACT A CONSTANT commands. After applying the reverse command DIVIDE BY CONSTANT (e.g., 2), they saw the graphs change back. By comparing the numbers in the Data Table, Subjects found the relationship and understood the calculation process better.

It appeared that some subjects from the middle school and some subjects from high school had difficulty in understanding the changes on the computer graphs after they applied a calculation command to them. However, they explored some ways to understand how the calculation worked and under what conditions they could use them correctly. For example,

Subject 13 & Subject 14 tried the Calculate function after they collected data from the mass-spring oscillation (level two experiment). First, they chose Add a Constant command and entered 2, the wave moved up, but they did not recognize the change. Then they chose Subtract a Constant command and entered 2. The wave moved back to the original place. In order to test their result, they repeated the above procedure. This time they recognized what the Add a Constant and Subtract a Constant commands meant. They used the same procedure to figure out what Multiply by a Constant and Divide by a Constant commands meant. Subject 13 said, "PSL can be used to teach mathematics."

Subject 3 & Subject 4 explored the more advanced Calculate function after they collected the data from the Mass-Spring Oscillation (level two experiment). First, they chose the Differentiate from the curve of Distance-vs.-Time. The shape of the new curve became the same as the curve of Velocity-vs.-Time. Second, they chose the Integrate from the Velocity-vs.-Time curve. The curve changed to the shape of the Distance-vs.-Time. Subject 4 concluded that the "differentiate" of Distance vs. Time was the velocity and the "integrate" of Velocity vs. Time was the distance. Subject 3 understood these mathematical processes by comparing the addition and subtraction, "they are reverse operations."

Subject 22 was a computer science and a mathematics major. He was interested in the calculation option. He understood more about calculations than the other subjects. Based on his experiment results, he tried ADD A CONSTANT, SUBTRACT A CONSTANT, MULTIPLY BY A CONSTANT, DIVIDE BY A CONSTANT, DIFFERENTIATE and INTEGRATE commands. He understood the calculation process very well and he used the same methods as Subject 13 & Subject 14, and Subject 3 & Subject 4. Subject 22 knew that some calculations, such as LOG(base 10), ANTILOG(10th power), SQUARE ROOT, RECIPROCAL, POWER, SINE and COSINE, must meet unique mathematical conditions. If the needed conditions were not satisfied, the calculation process would not proceed or the calculation results would not be accurate. In order to apply these calculations to the data, one needed to adjust the data so that they fit the mathematical conditions. For example, LOG (base 10) command does not allow a zero point. In order to use LOG(base 10) in the PSL, the user must eliminate all zero points. In addition, some commands have different formats in the various programs. For example, the SINE command uses the form Sin(2π ft +ø) and π is replaced by PI() in most spreadsheets and on graphs calculators. The PSL, SINE function uses the form Sin(360ft+ø). Since Subject 22 could not find this information from the PSL manual, he discovered his own method to figure out how the calculation process worked and under what mathematical conditions he could use each calculation. After he figured them out, he said, "I feel confident in using these calculations." Refer to the following illustration stating how he understood the calculation process.

1) He exported a PSL file which gave the experimental data to MS WORKS and deleted other columns except column A (Time), he then created two new columns: column B with a formula, "= 360*1/2*A4" and column C with a formula, "= SIN(2*PI()*1/2*(A4))".

Then he saved this file as "SIN2PIFT.WKS"

File Edit Print Select Format Options View

=SIN(2*PI()*1/2*(A4))

SIN2PIFT.WKS

	A	B	C	D	E
2	8				
3	0.00000	0	0	.	
4	0.16478	$\boxed{29.659771}$	0.4948487		
5	0.32955	59.319541	0.8600263		
6	0.49433	88.979312	0.9998413		
7	0.65911	118.63908	0.8776562		
8	0.82388	148.29885	0.5254887		
9	0.98866	177.95862	0.0356212		
10	1.15344	207.61838	-0.46358		
11	1.31821	237.27817	-0.841305		
12	1.48299	266.93793	-0.998572		
13	1.64777	296.59771	-0.894172		
14	1.81254	326.25747	-0.555462		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		
.	.	.	.		

Created a second column with the formula:
=360*1/2*A4

Created a third column with the formula:
=SIN(2*PI()*1/2*(A4))

Figure 4-29 Two columns with formulas =360*1/2*A4 and =SIN(2*PI()*1/2*(A4))

2) He used PSL to open file, "SIN2PIFT.wks", the following graphs were displayed:

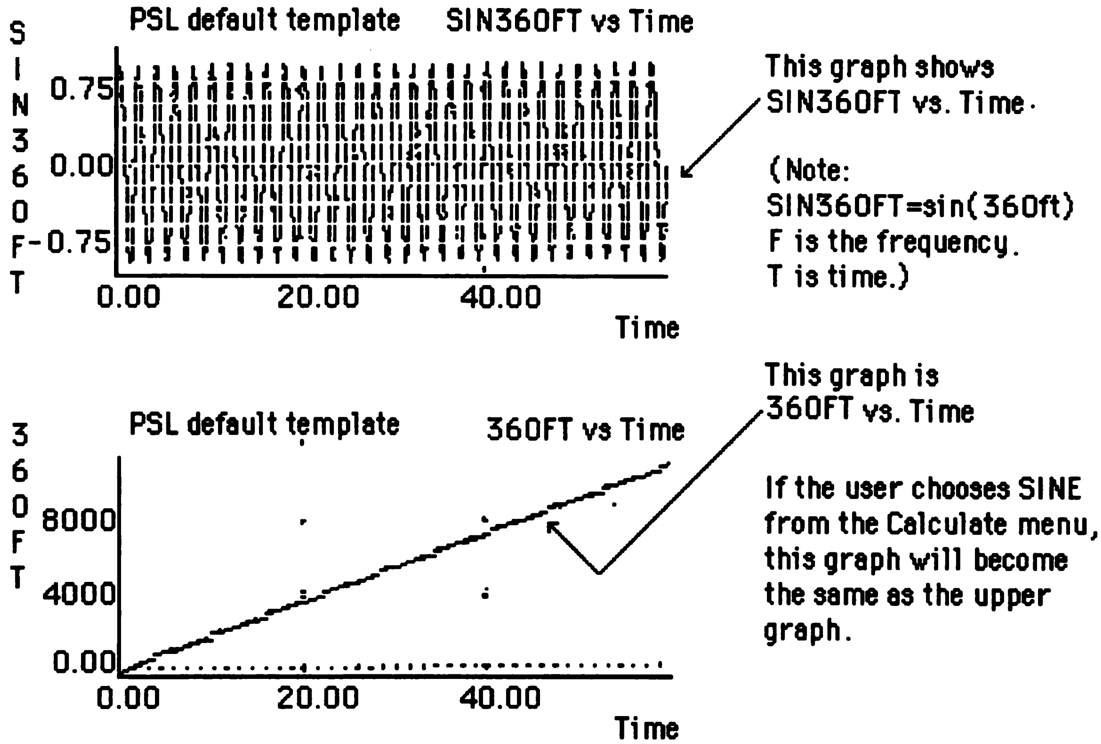


Figure 4-30

3) He made the lower graphs active and chose SINE (360 degree) function. The lower graph became the same as the upper graph.

Through the above exploration, Subject 22 found that the conditions in using the SINE command in PSL and in MS WORKS were different: In the PSL program, one must use 360 degrees and in MS WORKS one must use 2π.

He used the same method to find the conditions of using the COSINE correctly.

Discussion:

According to Sherry Turkle's findings, children who were nine or older were in the third stage and their performance were reflections of their minds. All the subjects in this study were older than nine and would have been in the third age level category. Their performances while using the computer program reflected their thinkings. Subjects 13 & 14 (middle school students), and Subjects 3 & 4 (high school students) understood the calculation processes in the PSL by using the reverse operation. Once the calculation results on the computer screen matched their mental image, they understood the calculation processes. Subject 3 was taking Introductory Analysis at that time, and knew the concepts of differentiate and integrate, but had not used them to solve a physics problem like the Mass-Spring Oscillation. Subject 4 was taking physics at that time, but had not learned how to differentiate and integrate. Subjects 3 and 4's explorations helped them find the relationship between Differentiate and Integrate. Subject 3 said, "they are reverse operations."

One thing should be pointed out: the reverse operation was not available for some calculations in the PSL program, such as POWER, SINE and COSINE. A person with a very strong background in mathematics and computer science, like Subject 22, would not feel confident in using the computation in PSL. They needed to fully understand under what mathematical conditions they could use these calculations confidently. In order to do so, the PSL program should provide some ways to help users understand easily how the calculation process works. Because the PSL did not provide enough capability for Subject 22 to do this kind of exploration, he used MS WORKS to determine under what mathematical conditions he could used the calculations correctly.

Since the subjects from middle school had not learned the functions of the graphs in their mathematics classes, they were not accustomed to reading the changes that appeared on the graphs. For example, when a Mass-Spring wave moved up 2 places after they chose ADD A CONSTANT and entered 2, some of them were not able to find the changes because the wave shape was still unchanged. Only the values on the axis changed. It would be useful for the PSL program to provide some guided practices for users to understand the calculation process. For those calculations which have reverse operations, it appears helpful to guide students to use the reverse operation in order to increase their understanding of the calculation processes. For those calculations which do not have reverse operation, it seems important to allow them to input a formula to test their calculation so that they understand under what mathematical conditions they can use them correctly.

A subject from the seventh grade commented, "The PSL can be used to teach mathematics." This raised an interesting point: Could a teacher take advantage of the PSL to teach mathematics? One result of this study indicated that subjects from middle school were not accustomed to reading the changes that occurred from the graphs after they performed a calculation. How then could the PSL be used to teach mathematics? The questions here are, "Should students learn the graphs of functions in the mathematics class first in order to read the PSL graphs? Could a teacher take advantage of the PSLs capabilities, such as 1) immediate feedback, 2) high interaction, 3) reverse operation and 4) data presented in both graphs and Tables, to teach the graphs of functions?" Further discussion will be included in Chapter five.

Finding 4: There were three high school students, five middle school students and one graduate student who tried the calculation commands in the PSL. They tended to understand how the calculations worked and under what conditions they could use them correctly. It took quite some time for subjects from middle school to understand what changes occurred on the computer graphs after they chose simple calculations. They subsequently understood the calculation processes by using the reverse operations and by comparing the data in the Table and the data presented on the graphs. For some calculation commands, reverse operations were not provided; at least one subject discovered his own method to determine under which conditions they could be used correctly.

Research Foci Five: To what extent do computer graphs help subjects understand the subject-matter knowledge of physics and mathematics?

The data presented in the previous section indicated that the tabular data helped the subjects from the middle school understand the relationship between the changes and the calculation commands after they applied ADD A CONSTANT and SUBTRACT A CONSTANT to a Mass-Spring wave. It seemed that they identified the changes from the tabular data better than they did from the graphical data. However, the following examples illustrate that the computer graphs helped subjects understand the subject-matter in different perspectives.

When viewing computer graphs like Temperature vs. Time, Distance vs. Time and pH vs. Time, subjects were not only able to tell how much the temperature, distance or pH value changed; they were also able to tell which temperature, distance or pH value changed faster and how the graphs changed. The "real-time" computer generated graphs helped the subjects get a broader view of how the variables changed in the experiments. This suggests that the PSL computer graphs helped subjects understand the subject-matter knowledge better.

There are six examples from level one and two in this section. Each example illustrates different aspects of the PSL graphs and how these graphs helped subjects understand the subject-matter knowledge of physics, chemistry or mathematics. The following overview may help understand the subsequent detail.

Example 1: A subject in eleventh grade, when performing a pH experiment, said, "It take time to stabilize." (level two experiment)

This example shows how the PSL graphs helped Subject 1 learn that stabilization of the pH probe took much longer than he expected, even though he was a lab assistant in a chemistry class at that time.

Example 2: A subject in ninth grade, when performing a temperature experiment, said, "There is a little pot." (level one experiment)

The PSL graphs helped Subject 2 learn not only how much the temperature changed (the end result), but also how it changed (the changing process).

Example 3: Two eighth grade subjects, when exploring a two-probe temperature experiment, stated, "What made this different." (level one experiment)

Subjects 9 & 10 found an interesting phenomena with the help of the PSL graphs. Their casual finding enhanced their understanding about temperature.

Example 4: A seventh grade subject, when analyzing the temperature experimental data, said, "It is different from what I feel." (level one experiment)

With the help of the PSL graphs, Subject 11 concluded that the room temperature was lower than the cold water in that room. This enabled him to realize that subjective feeling was different from objective measurement.

Example 5: Two eleventh grade subjects, when exploring the calculation commands, stated, "The derivative of distance respect to time is the same as velocity" (level two experiment)

By exploring the calculation functions and the computer graphs in the PSL graphs, Subjects 3 & 4 understood some mathematical concepts with a physics application. The PSL graphs helped them to establish a relationship between abstract mathematics concepts and concrete physics phenomena.

Example 6: Two seventh grade subjects, when analyzing the experimental results, said, "It depends" (level one experiment)

This example showed that the PSL graphs assisted Subjects 13 & 14 to understand what phenomena occurred and under what conditions they occurred.

The following examples provide more detail.

Example 1: Subject one, when performing a pH experiment, said, "It takes time to stabilize" (level two experiment)

Subject 1 was taking a chemistry class at that time and was interested in using the pH probe to test the pH value of the drinking water in the fountain.

In the first experiment, he set-up a data collection for 60 seconds, the graph he produced is shown in Figure 4-31.

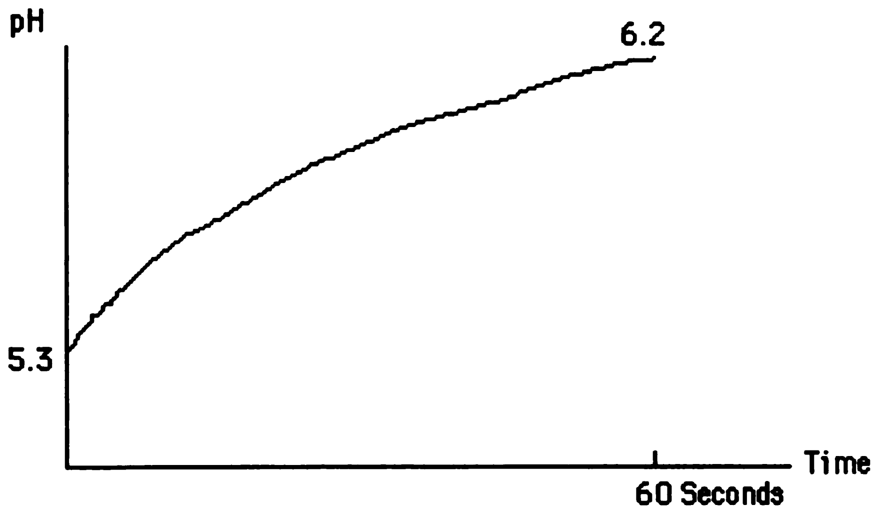


Figure 4-31 The pH value was increasing

From the graph, he knew the pH value was still increasing, so he repeated the experiment and obtained the second graph.

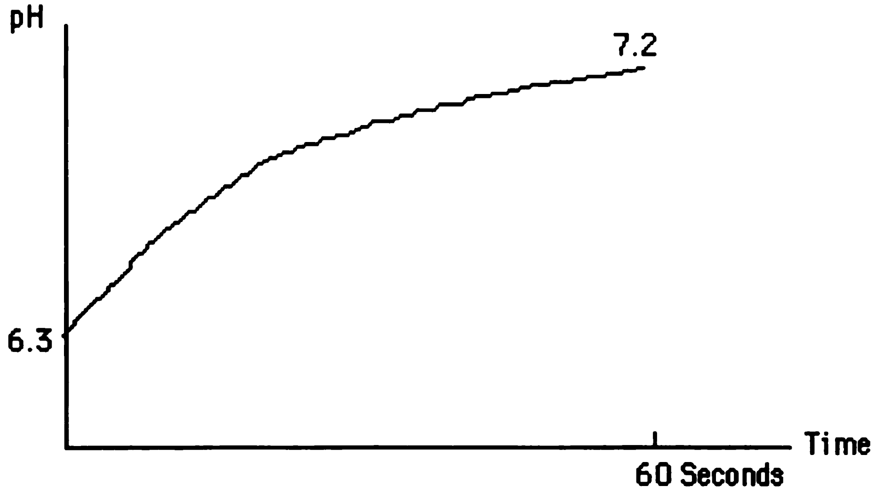


Figure 4-32 The pH value was still increasing

Because the second graph still showed the pH value increasing, he repeated the experiment one more time.

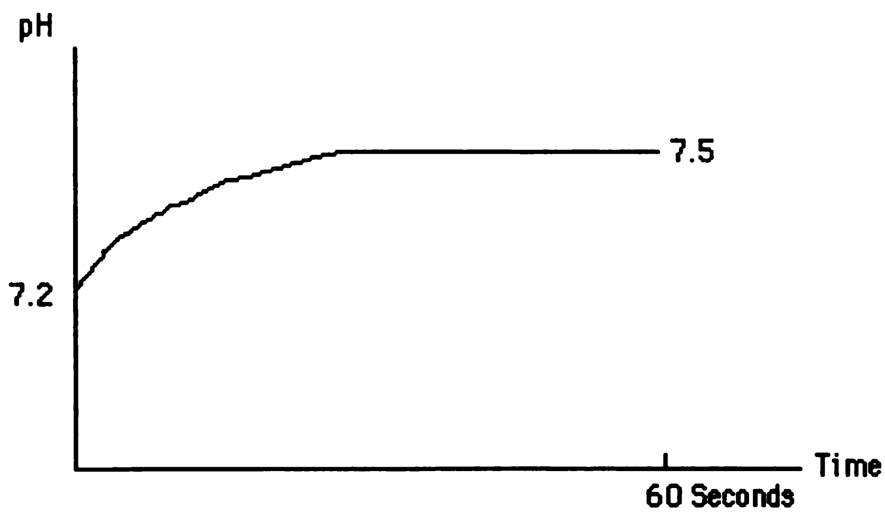


Figure 4-33 The pH value increased and then became stable at 7.5

The third pH graph showed that the pH value increased and then became stable at 7.5.

From the pH curves he stated that:

> The computer figured it out, left it in for a long time. It takes time to stabilize, it stabilized at about 7.5. (Note: the pH ranges from 0 to 14. Solutions with pH less than 7 are acidic, while solutions with pH greater than 7 are basic.)

Subject 1 did not initially realize stabilization would take so long. Because the pH was still increasing after the first 60 seconds experiment; he repeated the experiment two more times. After the experiment, he said that, "It (pH) took more time to stabilize." The "real-time" computer graphs helped him understand how long it took to stabilize the pH value, and which pH was the stabilized value.

Example 2: Subject 2, when performing a temperature experiment, said, "There is a little pot" (level one experiment)

Question: When you put the temperature probe into the cold water, will the temperature go down straight?

Subject 2 said, "It goes down, but there is a little pot."

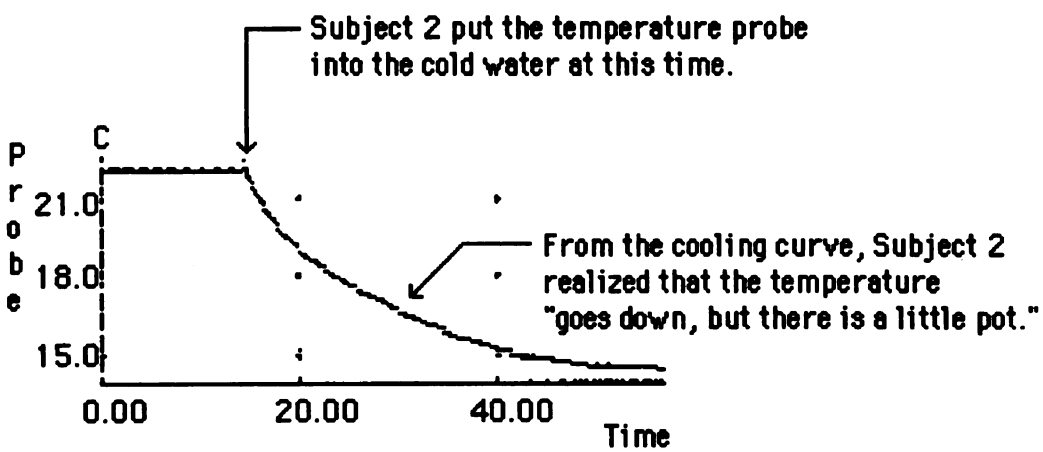


Figure 4-34 There was a little pot

Subject 2 was a ninth grade student. He had not learned Newton's law of cooling, but from the "real-time" computer graphs, he realized the cooling curve was not a straight line, "there is a little pot". The "real-time" computer graphs helped him understand how the temperature changed (the changing process), not just how much it changed (the final results).

Example 3: Subject 9 & Subject 10, when exploring a two-probe temperature experiment, stated, said, "What made this different" (level one experiment)

After Subject 9 and Subject 10 completed the first level experiments, they continued to experiment with the PSL. Subject 9 placed both temperature probes in the same container to see if probe A and probe B showed the same temperatures. The results showed that the short one (standard probe) displayed a higher temperature than the long one (extend probe). Subject 9 told Subject 10, "These two probes were different." Subject 10 looked at the computer graphs. The computer graphs showed the difference. Then she examined the two temperature probes and the container. She explained, "This was because these two probes were placed in a different spot, and the different spots had different temperatures in the same container. The short probe floated in the middle of the container, so it indicated a higher temperature, and the long one touched the bottom (closer to the ground) so it indicated a lower temperature."

Both Subject 9 and Subject 10 seemed to believe the computer graphs because they could view the two "real-time" computer graphs on the computer screen simultaneously. Subject 9 and Subject 10 explained the temperature curves in different ways. The interesting thing here was not whose explanation was correct. Rather, it showed that the computer graphs, which simultaneously displayed two different temperature curves, helped the students realize that the two probes indicated different temperature and stimulated the students to pose questions.

Later, the researcher tested both probes. The probes worked fine at that time. Subject 10's explanation was logical.

Example 4: Subject 11 & Subject 12, when analyzing the temperature experimental data, stated, "It is different from what I feel" (level one experiment)

When the computer program finished collecting data, the researcher asked Subject 11 and Subject 12 which graphs represented the temperature in the room and which one represented the temperature in the cold water and hot water.

Subject 11 stated, "The room temperature is right here, the cold water is higher (than the room temperature). This is a cold room."

Subject 11's findings from the computer screen surprised this author, because he felt cold when he used the cold water from the faucet before the experiment began. After he examined the temperature curves, he believed that the computer graphs were objective and that his feeling about the cold water must have been subjective. Subject 11's observation was correct.

Example 5: Subject 3 & Subject 4 , when exploring the calculation commands, stated, "The derivative of distance with respect to time is the same as velocity" (level two experiment)

After they collected the data from the Mass-Spring Oscillation, Subjects 3 &4 explored the mathematical function of PSL. First, Subject 3 chose Differentiate from the curve of Distance-vs.-Time. The shape of the new curve became the same as the curve of Velocity vs. Time. Later, Subject 3 chose Integrate from the Velocity vs. Time curve. The curve changed to the shape of the Distance vs. Time. Subject 4 concluded that: the derivative of Distance vs. Time was the velocity, the integration of Velocity vs. Time was the distance. Subject 3 understood these mathematics processes by recalling what she learned from an introductory analysis class.

Subject 3 had taken an introductory analysis class and was familiar with differentiate and integrate. She wanted to see how these calculations worked. Subject 4 was taking a physics class at that time. The real-time computer graphs showed them the connection between distance and velocity and helped them recall the knowledge they had learned in their analysis and physics classes.

Example 6: Subject 13 & Subject 14 , when analyzing the experimental results, stated, "It depends" (level one experiment)

Subject 14 said, "Does the temperature increase or decrease when you blow on the probe?"

Subject 13 said, "From here (they started blowing) it increased, from there (they stopped blowing) it decreased" as she pointed to the graphs on the computer screen.

The graphs showed how the temperature changed. Subject 13 was able to tell when the temperature increased and decreased. It helped her understand the conditions that caused the temperature to increase and under what condition the temperature decreased.

Discussion

Subject 1's chemistry teacher stated that Subject 1 was his lab assistant. From Subject 1's experiment with the pH probe, it was concluded that he underestimated the time for stabilization twice. Had Subject 1 used a traditional method (e.g. a pH meter) to test the pH value, it would have been possible for him to read the pH value after 60 seconds. If a traditional method had been applied, he would not have been able to find the correct pH value. However, the "real-time" computer graphs told him that the pH value was not stabilized after his first and second trial. He continued to run the experiment until he discovered that the pH value stabilized at 7.5.

When a cooling object is observed with a thermometer, it is not uncommon for middle school and high school students to focus on how much the temperature changes and ignore the important concept of how the temperature changes. This is because a regular thermometer is not sensitive enough and the students' observations are not fast enough to read the changes every 0.02 second (i.e. the sampling rate of the temperature probe). Therefore, students focus on the end results (i.e. how much it changed) and ignore the changing process itself (i.e. how it changes). However, the PSL is not only sensitive enough to show small changes, it is also able to display the changing process on the computer screen. This changing process stays on the computer screen as long as students need to read it (the experimental data stay on the computer screen until subjects delete them). This capability provided subjects an opportunity to observe something they were not able to observe in an experiment with a thermometer and allowed subjects to take as much time as they needed in order to examine and analyze the experimental results. Some subjects took advantage of this capability to learn something new. For example, Subject 2 viewed the experimental results from another perspective--how (i.e. the way it changes), Subject 11 found the room temperature was lower than the cold water from the faucet, and Subjects 13 & 14 understood the conditions that caused the temperature changed.

The capability of showing two graphs on the computer screen simultaneously helped subjects compare their experimental results or analyze the results. For example, it helped Subject 9 and Subject 10 discover a phenomena that the water temperature in the same container was not necessarily the same. It also helped Subject 3 and Subject 4 understand the relationship between the curve of Distance vs. Time and the curve of Velocity vs. Time.

What was the difference for the subjects from middle school between reading the graphs from a first-hand experimental data and reading the graphs after applying a calculation command (e.g. ADD A CONSTANT or SUBTRACT A CONSTANT)? When the subjects from middle school viewed graphs from the experiments, the changing processes from the graphs helped them make connections between the data and the physical phenomena. For example, when they saw the pendulum move far away from the motion probe and the indication of the distance on the computer graphs move upward, they understood that a "moved upward" in the computer graphs corresponded to "far away" in the pendulum experiment. In the temperature experiment, when they touched the temperature probe, the computer graphs moved up. So they understood that "moved up" in the computer graphs corresponded to "temperature increase" in the temperature experiment. In these situations, the difference is that the "real-time" experiment data provided a direct changing process, and the calculation process was not observed by the subjects. On the other hand, the final products of some calculation commands (e.g., ADD A CONSTANT and SUBTRACT A CONSTANT) did not change the shape of the graphs, only the number on the side of the Y-axis changed. It was difficult for a subject who had not learned the graphs of trigonometric functions to understand the meaning for these changes. In this situation, the tabular data provided by the PSL helped them find the changes, since all the numbers in the corresponding column changed and the subjects from middle school were accustomed to reading these kinds of changes.

Finding 5: Computer graphs helped subjects comprehend the subject-matter in different ways: i.e. viewing the experiment results from various perspectives, such as: how and how fast etc.; thinking about why; establishing relationship; and talking about the experiment more accurately. This led the subjects to understand the experiment results more readily. In order to read some computer graphs correctly, subject-matter knowledge was needed. It seemed that subjects from middle school read changes from the tabular data easier than from the graphs when they applied a calculation command.

Research Foci Six: Do subjects' attitudes towards the use of a computer change as they get computer experience while using the PSL?

Some subjects had never used computers, while some subjects had computer experiences before they participated in this research. All the subjects in this study were volunteers. They enjoyed using the PSL and had a positive attitude change after they used the PSL. The following responses and dialogues illustrate the subjects' attitude toward the PSL.

Table 4-10 Summary of the subjects' attitude toward the use of PSL

Subject (Year in school)	Their observed attitude while doing the PSL experiments.	What do you think about the PSL?	Do you want to learn more about the PSL?
Subject 1 (11)	Followed the instruction step-by-step.	(After completing leve 1) "Actually it is a very good program, but right now is not that challenging." (After completing level 2) "Educational, right now I just Know very basic......It is a good program, it would be a good program for college student."	Yes
Subject 2 (9)	Read the instruction carefully and followed the procedure step-by-step.	"It is easy to use."	Yes
Subject 3 (11)	Concerntrated on how the graphics changed on the computer screen.	"It is a lot of faster...... You don't have to write it down."	Yes
Subject 4 (11)	Gave suggestion to her partner and made two hypotheses and tested them.	"You don't have to check the experiment every two seconds."	Yes

Table 4-10, continued

Subject 5 & Subject 6 (8)	They read the instruction carefully and took turns pressing the keyboard keys. Sometimes they discussed ideas with each other.	Subject 6: "Very nice program, I like it."	Yes
Subject 7 & Subject 8 (8)	S.#7 often asked S.#8 for help before moving next step. S.#8 watched to the experiments very carefully, and she corrected S.#7's observations sometimes.	Subject 8: "It is an interesting program."	Yes
Subject 9 & Subject 10 (8)	Concentrated, strickly followed the instruction, did extra work after they completed the experiments at the first level.	Subject 10: "I think it is pretty easy." Subject 9: "It is easy to understand it."	Yes
Subject 11 (7)	Actively explored every thing; he was interested. Carefully compared his calculation results with the PSL computer graphics to find the errors in his calculation process.	"Very nice program."	Yes
Subject 12 (7)	Was 15 minute late. Watched how Subject 11 did the experiment for a while, then left.		
Subject13& Subject14 (7)	Both read the instruction very carefully, they signaled each other to press the computer keys.	Subject 14: "I like it." Subject 13: "It is pretty easy to use."	Yes
Subject15& Subject 16 (7)	Quiet, strickly followed the instruction.	"It is easy to use."	Yes
Subject17& Subject 18 (7)	Explored something they were interested in. Sometime they got lost, in this situation, they did it over.	"It is easy to use."	Yes
Subject19& Subject20 (7)	Very happy, enjoyed using PSL. They spoke out and talked a lot. They said "Cool !", "It is miracle." and "It is fun." quite often.	Subject 19: "It is cool." Subject 20: "Yes." Subject 19: "It is miracle."	Yes
S.#21&22 (Graduate students)	Concentrated.	"Good enough for research."	No
Subject 23 (Teacher)	Curious.	"I felt confident in using the PSL."	Yes

Discussion

In order to find some connections from the data in Table 4-10, the subjects were separated into two groups (The two groups were formed only for discussion purposes in this section). Group one includes subjects who had better computer/science experience. Group two includes subjects who had less computer or no / science experience.

Group one included: Subject 1, Subject 3, Subject 4, Subject 21 and Subject 22.

Subject 1 was an eleventh grade student. He knew several computer programs and had experience in spreadsheets. After he completed the first level, he said "the PSL is not that challenging." When he finished the second level, he realized the PSL could do much more than what he had anticipated. Then he changed his thinking and said "... it would be a good program for college students."

Subject 3 did not have much computer experience, but had a better background in chemistry and mathematics than other high school students. In chemistry class, Subject 3 read the temperature from a thermometer and recorded its changes on a piece of paper. After using PSL to do experiments, Subject 3 concluded that, "It (the temperature experiment) is a lot faster. You don't have to write it down." (Note: the highest sampling rate of the PSL was 34 times per second. It was impossible for a student to read the temperature change and recorded them on a piece of paper that quickly.)

Subject 4 was the only student who had taken physics among the grade school students and also knew how to use data bases and spreadsheets. She missed the first two experiments at level one and joined Subject 3 in the third experiment at level one. Upon completion of the third experiment (two temperature probes) at level one, she said, "You don't have to check the experiment every two seconds." As mentioned earlier, she measured the period of a simple pendulum by counting 1, 2, 3 ...... 16 and then divided the time by 16. By using the PSL, she discovered some differences that she did not find when experimenting with the problem in her regular physics class. As a matter of fact, she formulated two hypotheses and used the PSL to test them. The capabilities of the PSL encouraged her to investigate the simple pendulum problem in more depth than she had done in her regular physics class.

Subject 21 had a very strong background in mechanical engineering and computer science. After completing four approximations, he was impressed with the PSLs potentials. He thought both sample rate (34.1 samples/second for the motion probe) and the accuracy (six significant digits) of the PSL were adequate for research usage.

Subject 22 recalled that his friend (a Ph. D candidate in Crop and Soil Science) recorded the temperature day and night. He said the PSL could help his friend save time and energy, since the PSL was able to collect temperature data and save the data in the computer.

The more the subjects learned about the PSL, the more new ideas they generated using the PSLs capabilities. Some of them were immersed in exploring something. For example, both Subject 21 and Subject 22 spent three consecutive hours in learning and applying the PSL. They were impressed with PSLs capabilities after they used it.

Group two included: Subjects 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 and 23.

These subjects had little computer experience and/or science background. Table 4-10 shows that most of them were very quiet and followed strictly the prescribed procedures to perform the experiments in level one. They did not try alternatives. After they completed level one, all of them stated that: "The PSL is easy to use.", "The PSL is an interesting program." or "I like it." It appeared that their satisfaction with their success in experiments enabled them to feel confident in using the PSL. Some subjects tried some alternatives or something new. For example, 1) After Subjects 9 and 10 completed the two temperature probe experiment, they placed two temperature probes into the same water container. An interesting thing happened: two temperature probes in the same water container indicated two different temperatures. This differed from their previous experiment which they placed one temperature probe in cold water and another in hot water. Therefore, they actively tried to find a reasonable explanation in order to understand this phenomena. (For details, see research question five) 2) After Subject 11 completed level two experiment, he was interested in the Fit-line equation. Actually, he did not know what Fit-line meant. The interesting thing was that the PSL encouraged him to explore something beyond his knowledge and he was immersed in doing this exploration after he knew how to use the PSL (for details, see research question two). 3) When Subject 13 understood the calculation process, she stated:" PSL can be used to teach mathematics" (for details, see research question four). These examples indicated that once these participants became comfortable users of the PSL, they sought more creative ways to use it.

Most of the subjects in this group seldom talked. However, two pairs of subjects talked constantly. The following dialog is only a sample of their conversations.

Pair one: Subject 7 & Subject 8 (level one experiment)

Subject 8 said, "Highlight graph, let me do it."

Subject 7 said, "Do you want to do it ?"

Subject 8 said, "Read it for me."

......

Subject 8 & Subject 7 said, " Zoom into the marked region."

(When they saw the enlarged area)

Subject 7 said, "It's a miracle."

Subject 7 never used a computer for academic purpose except playing computer game before she used the PSL. Subject 7's teacher said she was not a smart student. However, she was not afraid to try. Subject 8 knew wordprocessing, but she never used the PSL. While Subject 8 was still reading the instruction, Subject 7 followed the instruction and started the PSL. After watching how easily Subject 7 used the PSL, Subject 8 felt confident in using it too. She wanted to switch the position and asked Subject 7: "Let me do it." Subject 7 seemed to feel proud of herself and replied: "Do you want to do it?" Subject 8 said: "Read it for me." While Subject 8 was pressing keys on the keyboard, Subject 7 was actively keeping her eyes on what was happening, on the computer screen. Their conversation suggested that Subject 8 was eager to operate the PSL once she realized it was easy to use. Their conversation also suggested that Subject 7 felt confident after she successfully started the PSL and became an active participant. For those experimental results obtained by using the PSL, they exclaimed, "It's a miracle."

Pair two: Subject 19 and Subject 20 (level one experiment)

Subject 19 said, "Then touch the probe, wave it in the air, or blow on it."
(Both tried the probe these ways.)

Subject 20 said, (While watching how the temperature changed)" This is fun."

......

Subject 19 said," Type Z" (Zoom in).

Subject 20 said, "OK." (She typed Z and the graphs she had marked became enlarged)

Subject 20 said, "Oh, you have to type Z !" (She was surprised and laughed for a while)

Subject 20 said, "Oh, look at, look at... " (She pointed to the enlarged graphs.)

Subject 19 said," Cool !"

......

Subject 19 said, "Yes, it is cool."

Subject 20 said, "This is fun."

Subject 19 and Subject 20 had known each other since fifth grade. Their conversation was very informal and the above conversation was just one example of their experimentation. Actually, the researcher heard "fun", "cool" and "miracle" from them all the time. The more capabilities of the PSL they learned, the more they said the PSL was "fun", "cool" and a "miracle".

Finding 6: After completing level one, all the subjects stated that: the PSL was a very good program and was easy to use. All of them had a positive attitude toward the use of the PSL. For those subjects who had more computer or science experience, the more they used the PSL, the more they learned that the PSL could be used. The graduate students thought it was good enough for some types of research studies. For those subjects who had less computer or science experience, the more they tried the PSL, the more they liked it and felt more confident in using it.

Research Foci Seven: Do subjects who have both computer skills and subject-matter knowledge interact with the PSL differently from those who do not?

Table 4-11 shows subjects' computer background and Table 4-12 shows subjects' subject-matter background.

Table 4-11 Subjects' computer background

	Subject #																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Had used a computer?												No information (was late and left early)											
at home		X		X	X	X			X	X											X	X	
at school	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Software experience?																							
computer game	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X			
word processing	X	X	X	X				X	X	X	X		X	X					X	X	X	X	X
data base	X			X																	X	X	
spreadsheets	X			X																	X	X	
statistical analysis software																					X	X	
math, science and engineering software																					X	X	
programming language				X																	X	X	
Hours spent/per week																							
less than 2					X	X	X								X	X	X	X					
2-5		X	X					X	X	X	X		X	X					X	X			
over 5	X			X																	X	X	X
Had taken computer class?	X		X	X																	X	X	

Table 4-11 indicates that Subjects 1, 4, 21 and 22 had more computer experience than other subjects.

Table 4-12 Subjects' subject-matter background

	Subject #																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Taken general science in middle school or high school?	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Taken chemistry in high school?	X		X	X																	X	X	X
Taken algebra II in high school?	X		X	X																	X	X	X
Taken introductory analysis in high school?			X																		X	X	
Taken physics in high school?				X																	X	X	
Taken physics in college?																					X	X	
Majors																							
mechanical engineering																					X		
mathematics																						X	
computer science																						X	

Table 4-12 indicates that Subjects 1, 3, 4, 21 and 22 had more content subject-matter knowledge than other subjects.

The results of the survey on Table 4-10 and Table 4-11 suggested that Subjects 1, 3, 4, 21 and 22 had more computer skills and content subject-matter knowledge than other subjects.

In order to discuss whether subjects who have more computer skills and content subject-matter knowledge interacted with the PSL differently from those who do not have these skills and knowledge, the author separated the subjects into two groups:

Group one: This group had better computer and science content experience. This group included Subjects 1, 3, 4, 21 and 22.

Group two: This group had less computer and science content experience. This group included Subjects 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 and 23.

Most of the data in Table 4-13 and Table 4-14 are based on the data presented in the previous sections. These two tables summarize subjects' abilities in using the PSL.

Table 4-13 Summary of subjects' interaction in group one

Subject #	Levels completed: one	two	three	Tried alternatives while following the prescribed procedures to perform experiments in level one?	Was able to make connection with prior knowledge in order to understand experimental results?	Was able to formulate hypothesis for further investigation?	Was able to formulate procedures which the manual did not provided?
1	X	X		Yes	Yes	Yes	Yes
3	X	X		Yes	Yes	Yes	No
4	X	X		Yes	Yes	Yes	Yes
21	X	X	X	Yes	Yes	Yes	Yes
22	X	X	X	Yes	Yes	Yes	Yes

Table 4-14 Summary of subjects' interaction in group two:

Subject #	Levels completed: one	two	three	Tried alternatives while following the prescribed procedures to perform experiments in level one?	Was able to make connection with prior knowledge in order to understand experimental results?	Was able to formulate hypothesis for further investigation?	Was able to formulate procedures which the manual did not provided?
2	X	X		Yes	Yes	No	No
5	X			No	No	No	No
6	X			No	No	No	No
7	X			No	No	No	No
8	X			No	No	No	No
9	X			Yes	No	No	No
10	X			Yes	No	No	No
11	X	X		Yes	Needed clue	Yes	No
12	(Was late and left early)						
13	X	X		Yes	Needed clue	No	No
14	X	X		Yes	Needed clue	No	No
15	X			No	No	No	No
16	X			No	No	No	No
17	X			No	No	No	No
18	X			No	No	No	No
19	X	X		Yes	Needed clue	No	No
20	X	X		Yes	Needed clue	No	No
23	X	X		Yes	Yes	No	No

Table 4-15 Generalization of Table 4-13 and Table 4-14 by comparing Group one and Group two:

	Levels completed: one	two	three	Tried alternatives while following the prescribed procedures to perform experiments in level one?	Was able to make connection with prior knowledge in order to understand experimental results?	Was able to formulate hypothesis for further investigation?	Was able to formulate procedures which the manual did not provided?
Group one (Five subjects)	5 100%	5 100%	2 40%	5 100%	5 100%	5 100%	4 80%
Group two (Eighteen subjects)	17 94%	7 39%	0 0%	9 50%	2 11%	1 6%	0 0%

• In group one, five of five subjects (100%) completed level one. Five of five subjects (100%) completed level two. Two of five (40 %) subjects completed level three.

In group two, seventeen of eighteen (94%) completed level one. Seven of eighteen subjects (39%) completed level two experiments. Zero of eighteen (0 %) subjects completed level three experiments.

• In group one, five of five subjects (100%) tried alternative methods while following the prescribed procedures to perform experiments in level one.

In group two, nine of eighteen subjects (50%) tried alternative methods while following the prescribed procedures to perform experiments in level one.

• In group one, five of five subjects (100%) were able to make connection with prior knowledge in order to understand experimental results.

In group two, two of eighteen subjects (11%) were able to make connection with prior knowledge in order to understand experimental results. Five of eighteen subjects (28%) needed clues in order to make connection with prior knowledge for understanding experimental results.

• In group one, five of five subjects (100%) were able to formulate hypothesis for further investigation.

In group two, one of eighteen subjects (6%) were able to formulate hypothesis for further investigation.

• In group one, four of five subjects (80%) were able to formulate procedures which the manual did not provide.

In group two, zero of eighteen subjects (0%) were able to formulate procedures which were not in the PSLs manual.

In general, group one had a high percentage in participating in a high level of experiments, such as trying alternatives, making connection with prior knowledge and formulating new procedures.

The followings provide more details about the differences of group one (had better computer while science content experience) and group two (had less computer and science experience). Their differences are compared within five categories:

1) Ability to participate in higher levels of experiments

Table 4-13 and 4-14 show that group one had higher percentage of subjects who participated in higher level of experiments. These data indicate that the more computer and science knowledge that subjects had, the more likely they were to participate at a higher level of usage of the PSL.

2) Ability to try alternatives while following the prescribed procedures to perform experiments in level one

a) Subjects in group one:

All subjects in group one tried some alternatives in the level one experiment. For example, they tried different experiment set-ups or tried a different way to alter the temperature on the temperature probe. Trying alternatives meant that subjects did something which the prescribed procedures did not define. For example,

Subject 1: In the simple temperature experiment, the prescribed procedures asked subjects to choose One Temperature vs. Time experiment set-up to collect temperature data. Upon completion of the experiment, Subject 1 selected Two Temperature vs. Time set-up to measure the temperature.

Subject 3: To practice the reset parameters commands, the prescribed procedures asked subjects to set up two of reset parameters, i.e. Duration... and Ranges of axes..., in level one activity 2---Creating an Experiment. Subject 3 tried another parameters command, i.e. Axis variables....

Subject 4: In level one activity-3---Selecting and Running a Two-Probe Experiment, Subject 4 suggested Subject 3 choose Type of Plot command and select Points to see how the computer graphs changed.

Subject 21: Upon completion of level one activity-3, Subject 21 used the Two-probe experiment to test how the Calibrate command worked. In his experiment, he calibrated probe A with the number that was indicated on probe A and he did not calibrate probe B (i.e. used 500 as the default value). Then he placed both probes on the desk to measure the room temperature in order to see the difference.

Subject 22: In order to change the experiment set-ups, he tried all the Reset parameters commands, i.e. Axis variable..., Duration..., Labels..., Numeric format..., Ranges of axes... and Type of plot....

b) Subjects in group two:

Nine subjects in group two tried alternatives, eight other subjects in group two strictly followed the prescribed procedures. For example,

Subject 2: After following the procedures to place the temperature probe in the cold water first and then place it in the hot water, Subject 2 tried an alternative way of placing the temperature probe in the hot water first and then in the cold water.

Subjects 9 and 10: After they completed the level one activity in which they placed two temperature probes in two different beakers, they then placed two temperature probes into the same water container and found these indicated two different degrees of temperature. (See research question five for details)

Subject 11: In practicing the View command in the level one activity-3, a small window showed that Temp A was in Port 1, Channel 1 and Temp B was in Port 1, Channel 2. Subject 11 tried to change the port number, but was unable to do so. Although his trial was unsuccessful, he did try an alternative.

Subjects 13 and 14 used two temperature probes to test their hand temperatures after they completed level one activity -3. They selected the Two Temperatures vs. Time experiment set-up and each person held one temperature probe to compare their hand temperatures.

Subjects 19 and 20 did some alternative experimenting with the Two Temperature vs. Time experiment. After they tried with one temperature probe in the cold water and the other one in the hot water, they pulled out the one in the cold water and placed it in the hot water, so that the two temperature probes were in the same hot water container at the same time.

Subject 23 put the temperature probe into the cold water and then pulled it out. He did this several times and created very interesting graphs. (See research question nine for details)

Subjects 5, 6, 15, 16, 17 and 18 did not try any alternatives when they performed the level one experiments. They did not speak of their thoughts aloud. They strictly followed the prescribed procedures while they were performing the temperature experiments. When they made a mistake or got lost, they simply started the experiment over. Subjects 15 and 16 completed level one with only one repetition. Subjects 5, 6, 17 and 18 completed level one with two repetitions.

Subjects 7 and 8 did not try any alternatives when they performed the level one experiments. However, they talked and thought aloud. (See research question eight for details)

3) Ability to make connections with prior knowledge in order to understand experimental results and the ability to formulate hypotheses

a) Subjects in group one:

All subjects in group one were able to apply their prior knowledge to understanding the experimental results. In addition, they were able to formulate some hypotheses based on their observations. For example,

Subject 1 measured the pH value of the drinking water in the fountain, his prior knowledge of chemistry helped him understand that the pH value took time to stabilize. However, the pH curve of the first 60 seconds did not convince him that the pH value had been stabilized. He stated: "It probably takes longer time to stabilize." In order to test, if the pH value took longer to stabilize, he repeated the experiment twice until he obtained a stabilized pH value. In this case, Subject 1's prior knowledge, that it would take time for the pH value to stabilize, played an important role in encouraging him to investigate whether the actual stabilization time of the pH value took longer than he had estimated. After he repeated the experiment twice, he concluded that "The computer figured it out, left it in for a long time. It takes time to stabilize, it is stabilized about 7.5." (See research question five for more details) In answering the question about the

pendulum clock, he was able to make connections among the variables of change of temperature, change of length and change of period.

Subject 3: In the level one experiment, all subjects from the middle school and three subjects from the high school who had not taken physics were not able to explain the difference between what they observed from the temperature probe and what they felt on their skin. Compared to the other subjects who had no physics background, Subject 3's response indicated that she was able to make a connection with her prior knowledge of science and formulated a hypothesis through this statement, "Maybe because your body temperature is higher than your breath, something like this." (See Table 4-3 in Research Question One) In answering the question about the pendulum clock, Subject 3 was able to make connection with the change of temperature, change of length and change of the period.

Subject 4's pendulum experiments demonstrated that her prior knowledge of simple pendulums played an important role in helping her to formulate two hypotheses. In her physics class, she counted 1, 2, 3 ...... 16 and divided the time by 16 in order to find the period of a simple pendulum. The simple pendulum experiment in her physics class was based on an assumption that each swing took the same time. The simple pendulum experiment on the PSL showed that the time interval of each swing was not exactly the same. The concepts she learned in her physics class and the experimental results she obtained from the PSL helped her formulate two hypotheses and test them. (See research question one for more details) In answering the question about the pendulum clock, Subject 4 was able to make connections among the change of temperature, change of length and change of period.

Subjects 21 and 22 faced a challenging phenomena concerning the simple temperature experiment. As mentioned earlier, they had a good background in physics. In an informal conversation, both of them admitted that when they took physics classes in college, they had already known the answers before they took the examination.

However, the PSL experiment created a challenging problem for them at that time. They were not sure what caused the difference. Their background in physics helped them formulate some logical assumptions in order to explain the phenomena. (See research question one for more details)

b) Subjects in group two:

On the other hand, only two subjects in group two were able to recall their prior knowledge of science in order to explain the difference between what they observed on the temperature probe and what they felt on their skin. For example,

Subject 2 said the cause of the difference was, "The temperature in the room is cold. When I blow on it (the temperature probe), it gets higher..."

Subject 23 stated that the cause of the difference was evaporation.

Subjects 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20 had no theories about causations of the difference.

In answering the question about the pendulum clock, subjects in this group (i.e. 11, 13, 14, 19 and 20) were able to make connections with the change of temperature, change of length and change of period when they were provided the clue, "Will the pendulum become longer or shorter when the temperature is higher?"

One Subject (i.e. Subject 11) was able to formulate some hypotheses about the Fit-line equation of the marked points. (See research question two)

4) Ability in formulating new procedures

a) Subjects in group one:

Subjects 1, 4, 21 and 22 were able to formulate some procedures which the PSL manual did not provide in order to accomplish their tasks. For example,

Subject 1: In the level two experiment, he created a new procedure to establish an experiment set-up to show the relationship between temperature and pH value. The following is the procedures he created:

First he created a coordinate under the software's Temperature option.

Figure 4-35 A set-up of Temperature vs. Time

Secondly, he changed the X-Axis variable from Time to pH.

Figure 4-36 A set-up of Temperature vs. pH

Finally, he accepted this experiment set-up and started collecting data. Because other equipment needed to alter the temperature was not available at that time, both temperature and pH did not change considerably. This experiment showed that it was possible to collect two different kinds of data at the same time by using the PSL.

Subject 1's designs for the pH vs. temperature experiment set-up reflected his computer and mathematics background. The PSL manual did not state these procedures in this experiment's set-up at this time.

Note: This experiment set-up was successful. The researcher of this study was surprised by this new design. The PSL manual said: The PSL was able to collect up to 5 kinds of data at the same time. Unfortunately, the manual did not show how to do it. The researcher could not figure out how to do this before he saw Subject 1's findings. Subject 1's performance helped him discover how to collect five kinds of data at the same time.

Subject 3 did not create any new procedures.

Subject 4 tested her hypothesis about the time difference of each swing and discovered a new procedure to determine the time interval accurately.

When Subject 3 opened the Table from the top menu, a window showed the data of Time, Distance and Velocity. Subject 4 discovered a new way to measure the period from the Table.

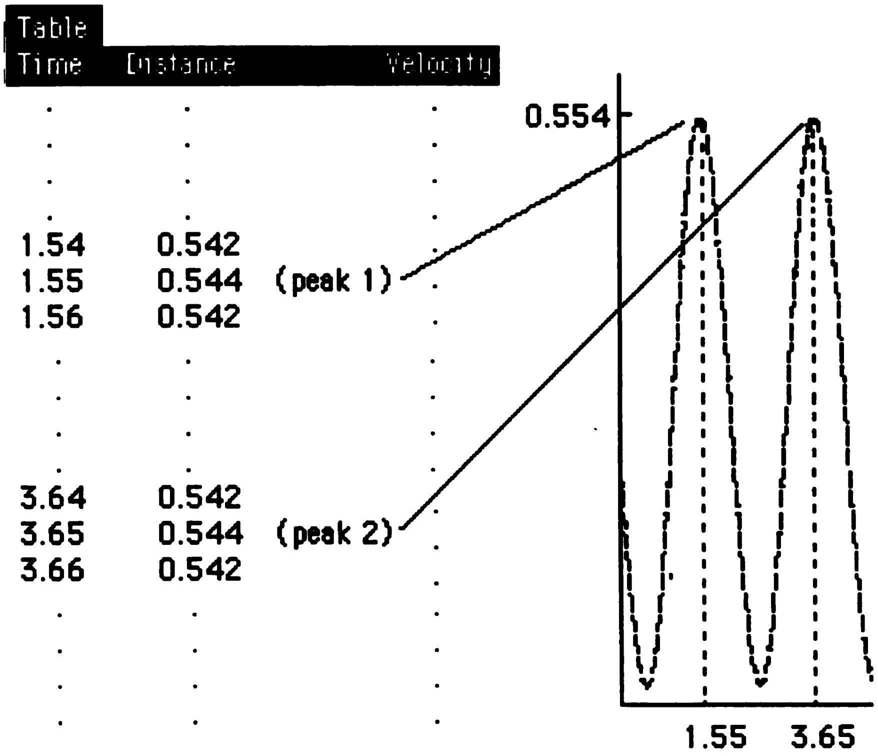


Figure 4-37 Subject 4's idea in finding the pendulum period

In this case, Subject 4 knew how to use computer spreadsheets while Subject 3 did not. When she saw Subject 3 open the Table from the top menubar, she discovered how to obtain the time interval between two peaks. Subject 3 saw the same Table, however, she did not realize that the data in the Table provided a more accurate way to determine the period because she did not know the concept of spreadsheets at that time. In order to find this new method to determine the time interval of each swing, a person needs to make a connection between the maximum displacement of a pendulum and the peak of a wave. In other words, Subject 4's discoveries reflected her computer and physics background. (See Research Question one for details)

Subject 21 was able to combine other programs like MS WORKS spreadsheets in order to complete some complex approximation. The new procedures he created involved a great deal of computer skills and knowledge of physics. (See research question three for more details)

Subject 22 was able to combine another program like MS WORKS spreadsheets to complete some exploration of the calculation commands. The new procedures he created involved a great deal of computer skills and mathematical knowledge. (See research question four for more details)

b) Subjects in group two:

Subjects 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20 and 23 did not create new procedures. They used only the PSL manual's procedures. They either strictly followed the prescribed procedures or looked for the instruction on the PSL manual to perform their experiments.

In this group, one subject (Subject 2) chose the pH probe to design an experiment set-up to collect pH value and temperature data simultaneously. His design could be used to compare with Subject 1's design. Subject 2 followed the instruction in the PSL manual to design his experiment set-up as follows:

First he created a coordinate like this:

Figure 4-38 A set-up of pH vs. Time

Second, he split the computer screen in order to collect two different sets of data from one experiment:

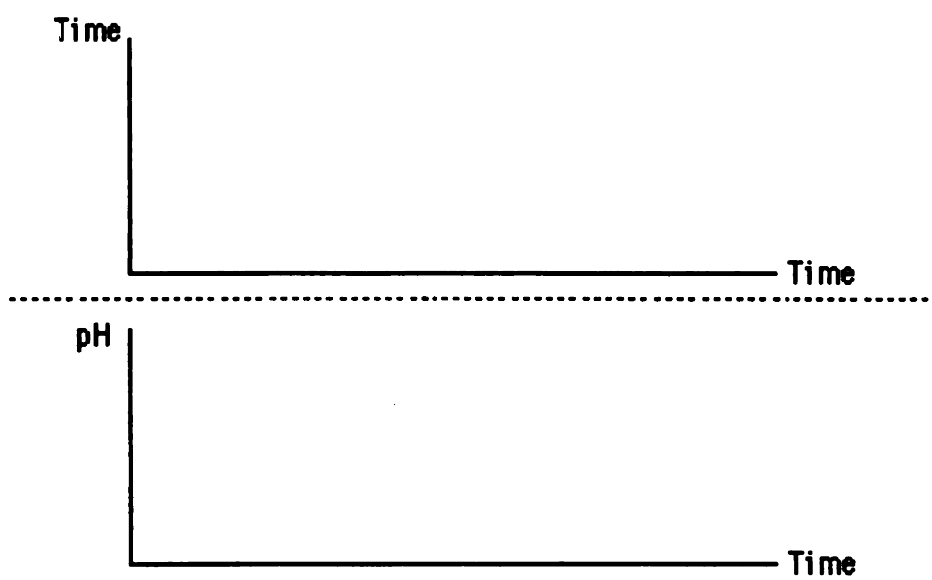


Figure 4-39 Creating a set-up to collect two kinds of data

Third, he highlighted the upper coordinate and designed the experiment set up as follows:

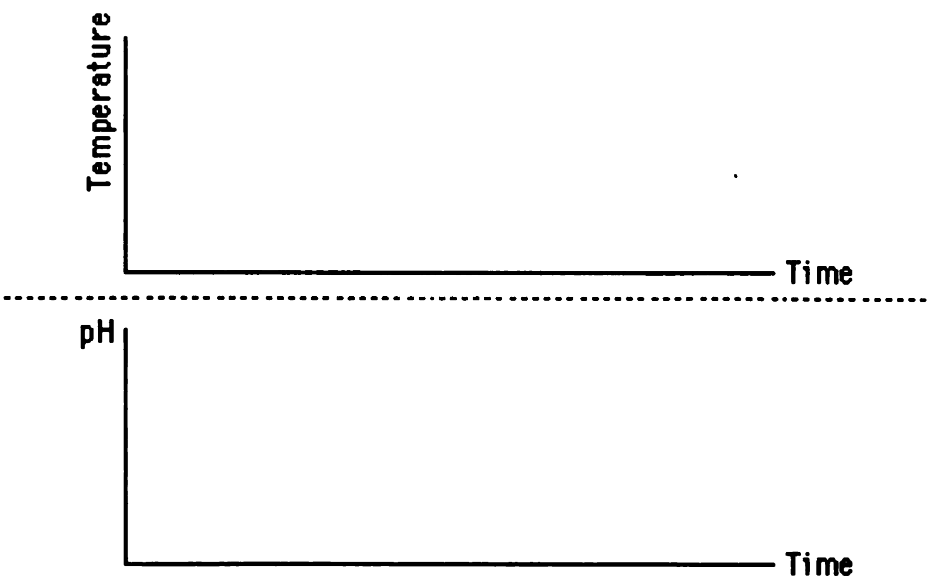


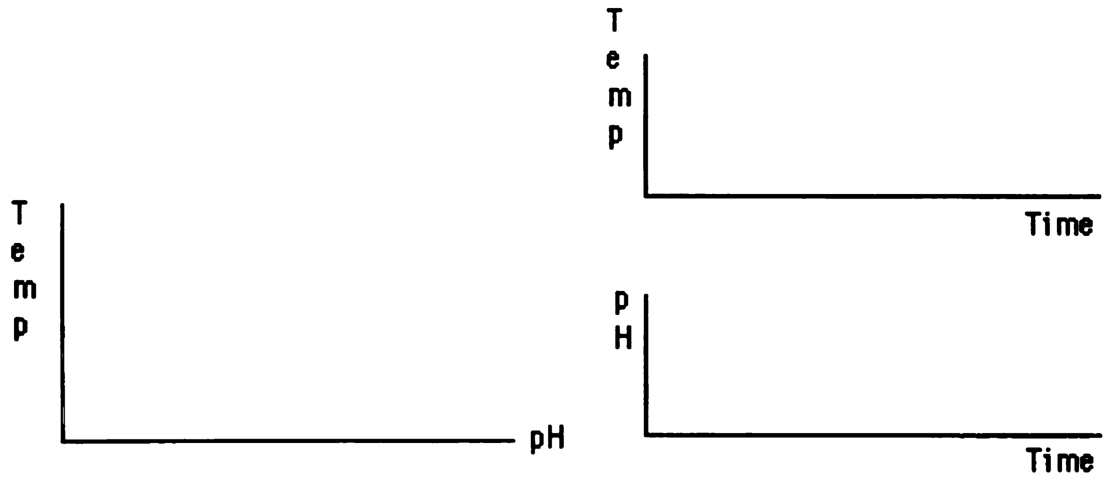
Figure 4-40 Subject 2's set-up of pH vs. Temperature

Discussion

The above data show that subjects who had more computer skills and subject-matter knowledge were more likely to participate at a higher level of PSL usage. They were more capable of using their prior knowledge in order to understand the experimental results and formulate their hypotheses. If the need arose, they were able to create some new procedures to accomplish their tasks. Subjects who had less computer skills and subject-matter knowledge were less likely to participate at a higher level of PSL usage. They seemed not to have enough prior knowledge to understand the experimental results and formulate hypotheses. In order to accomplish their tasks, they relied on either the prescribed procedures or the instructions in the PSL manual.

In this study, two subjects (i.e. Subject 1 and Subject 2) performed the pH experiments. It was interesting to compare their subject-matter background with their experimental set-ups. Subject 1 was an eleventh grade student and had learned the concept of Function in his mathematics class. Subject 2 was a ninth grade student who had not learned Function. In Subject 1's mind, everything he measured (including time) was a variable. Temperature was a variable; pH was a variable; Time was also a variable, so he could and did construct an experiment set-up of Temperature vs. Time, pH vs. Time, or Temperature vs. pH. In Subject 2's mind, everything he measured was vs. Time, Temperature should be vs. Time, and pH also should be vs. Time. Time was a special measurement.

Figure 4-41 compares Subject 1 and Subject 2's two experiment set-up for collecting two kinds of data (Temperature and pH value) at the same time. Their experiment set-up reflected their different mathematics background. Subject 1 understood the concept of function and Subject 2 did not understand this concept.



Subject 1's experiment set-up shows the relationship between temperature and the pH.

Subject 2's experiment set-up shows the relationship between temperature and the pH.

Figure 4-41 A comparison of Subject 1 and Subject 2's set-ups

Subject 1's design shows two kinds of data in the same coordinate because they are two variables of a function. Subject 2's design shows two kinds of data in two separate coordinates because he only knew that both temperature and pH changed as time progressed.

Some evidence indicated that subjects' interests also reflected their background. For example:

1) When Subjects 3 and 4 tried the differentiate and integrate commands on the simple harmonic motion wave, Subject 3 related the change to a mathematics concept and Subject 4 related the change to a physics concept. (See research question four for details.)

2) Both Subject 21 and Subject 22 had experience in using statistical analysis software, engineering packages/mathematics software, and programming languages. They knew that some computer software programs were able to exchange data with other programs. When the need arose and they realized that they could not accomplished their tasks using the PSL, they explored the possibilities of combining other computer software, such as MS WORKS and LOTUS 123. However, their interests were different. Subject 21's approximations (for details see section "What approximation skills do learners gain from the PSL?") reflected his background in engineering. He tried to explore some practical usage of the PSL. Subject 22's approach in determining the mathematical conditions of the calculation command in PSL, (for details see session "Do learners understand the calculation process when the PSL does all of the calculation?") reflected his background in mathematics.

Finding 7: Subjects who had better computer skills and more subject-matter knowledge in science were more likely to participate in the higher level experiments. They were more likely to recall their prior knowledge in order to understand the experiment results and formulated some hypotheses. Also, they were more likely to formulate new procedures to accomplish their tasks when the need arose. Some evidence showed that subjects' interests reflected their backgrounds (i.e. Subject 1's interest in doing the experiment reflected his chemistry background, Subject 4's interest reflected her physics background, Subject 21's interest reflected his mechanical engineering background and Subject 22's interest reflected his mathematics background).

Research Foci Eight: Does the PSL support and / or encourage collaborative learning?

In this study, some subjects worked individually and some worked in pairs in level one and level two. Table 4-16 shows their work style and the levels they completed.

Table 4-16 Subjects' work style and levels of completion

Subject	Year in school	Worked individually	Worked in pairs	Levels completed
Subject 1	11	X		levels 1 & 2
Subject 2	9	X		levels 1 & 2
Subject 3 & Subject 4	11	S. #3 completed Activity 1&2 in level one, then worked with S. #4 in Activity 3 in level one and level two.		
Subject 5 & Subject 6	8		X	level 1
Subject 7& Subject 8	8		X	level 1
Subject 9& Subject 10	8		X	level 1
Subject 11& Subject 12	7	S. #11 completed level one and level two. S. #12 was 15 minutes late and left early.		
Subject13& Subject14	7		X	levels 1 & 2
Subject15& Subject16	7		X	level 1
Subject17& Subject18	7		X	level 1
Subject19& Subject20	7		X	levels 1 & 2
Subject 21	Graduate stu.	X		levels 1, 2 & 3
Subject 22	Graduate stu.	X		levels 1, 2 & 3
Subject 23	Teacher	X		levels 1 & 2

This table shows that almost all the subjects from middle school and two subjects from high school worked in pairs. The researcher did not try to force collaborative. If a subject came individually, he/she worked individually. If subjects came with someone, they worked together. The following is a description of subjects who worked in pairs.

Subjects 3& 4:

Subject 3's chemistry teacher said she was a very good student; Subject 4's physics teacher said she was a very good student also. In this study, Subject 4 missed the first two experiments because of personal circumstance (she went to a blood drive). She joined Subject 3's experiment starting with activity three (Selecting and Running a Two-Probe Experiment) in level one. Since Subject 3 missed the first two experiments, she observed how her partner, Subject 3, performed the Selecting and Running a Two-Probe Experiment. When Subject 4 saw Subject 3 type in a name "T&R" in order to save the data that was collected, the computer showed "Invalid name", Subject 4 suggested to Subject 3, "You can't go with '&' sign." Then Subject 3 changed the name from "T&R" to "TandR". After that experiment they moved to the simple harmonic motion experiments, Subject 4 became more active. While Subject 3 was measuring the time interval of each pendulum swing, she formulated two hypotheses. In testing the second hypothesis, Subject 3 explored the Table menu on the top menubar, she discovered a new way to determine the time interval. Subjects 3 and 4 worked together and completed the Selecting and Running a Two-Probe Experiment in level one and the simple pendulum experiments in level two. (See research question one for more details) When they applied the Differentiate and Integrate commands to the Mass-Spring wave, Subject 3 understood the changes by relating to the concepts she learned from her Introductory Analysis class, Subject 4 understood the changes by relating to the concepts she learned from her physics class. Their prior knowledge (i.e. Subject 3' knowledge about the concepts of calculus and Subject 4's knowledge concepts of physics) supplemented each other's experimental application and helped them to make a connection between the abstract mathematics concepts and the concrete physics applications. (See research question four for details)

Subjects 5& 6:

Subjects 5& 6 had experience in computer games. They read the instruction on their own but they took turns using the keyboard. In Creating an Experiment, Subject 6 omitted steps and became lost twice. They started the experiment over. They did not share their thinking aloud. However, when they had a problem in understanding the instruction, they discussed it. They completed the level one experiments. They stated they would participate in level two, but never did.

Subjects 7 &8:

Subject 7 only had experience in computer games. Her science teacher said she was not an good student in her science class. However, she was not afraid to try. She started the PSL and collected the temperature data. Subject 8 had experience in word processing and her science teacher said she was a good student in her science class. She watched Subject 7 use the PSL for a while and said: "Let me do it." "Read it for me." Then they switched positions. While Subject 8 was using the keyboard, Subject 7 was actively keeping her eyes on what was happening on the computer screen. In answering the question, "Does the temperature increase or decrease when you blow on the probe?" Subject 7 looked at the graphs on the screen and said, "It decreased." Subject 8 pointed to the graphs on the screen and said, "No, it can go up, increases." From then on, Subject 7 always asked Subject 8 for confirmation. For examples, when she was not sure the next step, she asked Subject 8, "Now what I......" "What do you want? Probe A, B or C." "Is that 482 number?" "By the plastic wire?" "Próbe A? Which one is probe A?" It appeared that Subject 8 became Subject 7's opinion leader in these experiments.

Subjects 9&10:

Subjects 9 and 10 had experience in word processing. They seldom talked while they read the instruction and pressed the keys on the computer keyboard. However, when Subject 10 tried to get rid of a small warning window by pressing the ESC key, Subject 9 examined the screen and discovered the problem. She pointed to the figure on the screen and said, "Oh, it went higher, you have to get it back." Then Subject 10 realized that she had entered the number wrong. They completed level one successfully. After they completed level one experiment, Subject 9 put two temperature probes into the same water container. She found an interesting phenomena, the computer graphs showed that these two temperature probes indicated two different temperatures. Subject 9's finding initiated a conversation between them because they explained this phenomena in different ways. (See Research question five for details.) They stated they would participate in level two, but they did not do so.

Subject 11 &12:

Subject 12 did not complete level one. Actually, Subject 11 completed all the experiment by himself. Subject 11 had experience in word processing. He completed level one without any mistakes and participated in level two. He made some mistakes in level two. (See Research question two and five for details.)

Subject 13&14:

Subjects 13 and 14 had experience in word processing. They seldom talked about the experiments. They read the instruction on their own and signaled each other to press the computer keys in turn. In the simple pendulum experiment (level two), while Subject 14 moved the arrow to find the corresponding time of each trough, Subject 13 recorded the corresponding time and calculated the time interval of each swing. They completed level one accurately and participated in level two. (See Research question two, four and five for details.)

Subject 15&16:

Subjects 15 and 16 had experience in computer games. They did not discuss anything about the experiments. They read the instruction on their own and pressed the computer keys in turn. When they got lost once, they simply started the experiment over. They stated they would participate in level two, but never did.

Subjects 17&18:

Subjects 17 and 18 had experience in computer games. They did not speak or discuss their ideas aloud. They were interested in the graphs. After they chose the Zoom command and the Fit-line commands, they looked at the computer graphs for a while. When they returned to the manual's instruction, they got lost. They completed level one with two repetitions. They stated they would participate in level two, but never did.

Subjects 19 & 20:

Subjects 19 and 20 had known each other since fifth grade. They talked aloud. The following is part of their dialog:

When they found something new and exciting, they shared it with each other.

Subject 20 said, " It is going to straight apart."

Subject 19 said, "Let the experiment run for about 15 seconds to establish a graph of room temperature ......"

Subject 20 said, "Wait a minute !"

Subject 19 said, "Then touch the probe, wave it in the air, or blow on it."

(Both tried the probe these ways)

Subject 20 said, "This is fun." while they watched how the temperature changed.

When one had a mechanical problem in using the PSL and the other discovered the solution, they helped each other.

Subject 19 said, "Press ESC twice to remove the windows."

Subject 20 said, (Subject 19 was holding down the ESC key, while Subject 20 was typing the description, but Subject 19 could not remove the windows because Subject 20 had not finished typing yet.)

"You don't have to hold the ESC key down." (Subject 20 laughed at Subject 19.)

Subject 19 said, "Please let me know."

Subject 20 said, "Because......"(While Subject 20 was laughing, she pressed the Enter key to save the file, the windows were ready to removed)

Subject 19 said, "OK" (She realized the windows could be removed) .

Subject 20 said, "Now you strike (the ESC key) twice."

Subject 19 said, "(Pressed)ESC twice to remove the window."

Subject 20 said, "Ah-ha, you got it, finally."

The following is another example shows how they helped each other to solve another mechanical problem.

Subject 19 said, "What are you doing?"

Subject 20 said, "Enlarging it, in a minute."

Subject 19 said, "Move the pointer to the end of the area you want to examine, then type Z to enlarge the marked area."

(Subject 20 did not listen to Subject 19 carefully. When she finished marking, she kept pressing the Enter Key to enlarge the area she marked).

Subject 19 said, "Don't press Enter to try (to enlarge)."

Subject 20 said, "I'm going ahead." (kept pressing Enter Key, but she could not enlarge the graphs)

Subject 19 said, "Type Z "(Zoom in).

Subject 20 said, "OK (She typed Z and the graphs she marked were enlarged)

Oh, you have to type Z ! (Felt surprised and kept laughing for a while)

Oh, look at, look at... "(She pointed to the enlarged graphs)

Subject 19 said, " Cool !"

In order to locate the exact point where they took the probe out of the cold water, both of them watched carefully how the arrow moved on the computer screen and spoke out.

Subject 19 said, "Use the Right Arrow key to move the pointer to the place on the graph where you took the probe out of the cold water. Notice that the graph is highlighted as you move the pointer."

(Subject 20 was moving the Arrow key to highlight those points)

Subject 19 said, "Keep going."

Subject 20 said, "I know, I am thinking about these points."

Subject 19 said, "That's all, that's all."

Subject 20 said, "No."

Subject 19 said, "I'm sure the temperature (when you took the probe out of the cold water) on that place. (Subject 20 kept moving the arrow key), up here......"

Subject 20 said, "Ah, you got your mind."

"Back one, go back one."

Discussion

For pairs 3 &4, 7 &8, 9 & 10, 19 & 20, the observation in this study indicated that there were many benefits:

1) Shared experiences to solve the mechanical problems in using the PSL are listed:

a) Subjects found different methods to solve the file name. For example, Subject 4 told Subject 3 to change the file name from "T&R" to "TandR" and got out of the problem.

b) Subjects discussed solutions to solve the problem of the warning given in the windows. For example, Subjects 9 &10 worked together and found that they entered the higher figure 100 in the Mini and the lower figure 0 in the Max.

c) Subjects discovered how to remove the computer's window. For example, When Subject 19 could not remove the computer's windows on the screen, Subject 20 told Subject 19: "Now you strike (the ESC key) twice." In order to make sure she was doing it right, Subject 19 asked: "(Pressed) ESC twice to remove the window?" Subject 20 confirmed her: "Ah-ha, you got it, finally."

2) Questions that were raised about the data or given more attention were:

a) Subjects questioned the possibilities of various temperature readings. For example, Subject 9 and Subject 10 questioned why two temperature probes in the same water container indicated two different temperatures.

b) Subjects raised attention for their partner to observe the experiment results. For example, when Subject 20 saw the temperature graphs on the computer's screen change, she called Subject 19's attention," It is going to straight apart." (Note: the graph of the temperature was being drawn across the screen indicated that the computer was measuring the temperature of the room.)

When Subject 20 found the marked region was enlarged, she called Subject 19's attention again, "Oh, look at, look at... " Subject 19:" Cool !"

3) Subjects who discussed the data together:

a) Subjects discussed different data concerning temperature. For example, when Subject 7 and Subject 8 completed the simple temperature experiment, Subject 8 asked Subject 7, "Does the temperature increase or decrease when you blow on the probe?" Subject 7 said, "It decreased." Subject 8 disagreed, "No, it can go up, increases ."

b) Subjects discussed temperature events by using the indicator on the computer. For example, when Subject 19 and Subject 20 tried to exactly locate the point where they took the probe out of the cold water, Subject 19 said, "Keep going." Subject 20 said, "I know, I am thinking about these points." Subject 19: "I'm sure the temperature (when you took the probe out of the cold water) was on that place. (Subject 20 kept moving the arrow key), up here......" Finally Subject 20 said, "Ah, you got your mind. Back one, go back one."

4) Subjects' prior knowledge supplemented each other:

Subjects' prior knowledge of mathematics and physics supplemented each other and developed a higher level of understanding of the PSL experimental results. For example, Subject 3's mathematics background and Subject 4's physics background helped them understand that the "differentiate" of Distance vs. Time was the velocity and the "integrate" of Velocity vs. Time was the distance.

Pairs 5 & 6, 13 & 14, 15 & 16, 17 &18 did not talk to each other about the experiments. When some of them got lost, they did not ask questions and try to find the problems. In order to move on, they simply started the experiments over. They read the instruction on their own and pressed the keys on the computer keyboard in turn. Some even signaled each other to press the computer keys. Their performances looked as though they worked individually. The researcher did not find evidence which showed that they cooperated with each other. It seemed that working in pairs did not provide advantages for them. Later, the researcher talked to their science teachers. Their science teachers said these students seldom talked and rarely asked questions in their science classes either.

In this study, pairs 3 & 4, 9 & 10, 19 & 20 shared experiences to find mechanical problems and solve them. On the contrary, pairs 5 & 6, 15 & 16, 17 & 18 solved mechanical problems by simply restarting the experiments. From the observation, the researcher found that the mechanical problems that pairs 5 & 6, 15 & 16, 17 & 18 had were due to one of the partner's omitting steps or forgetting where they were. Since they did not talk aloud, they probably did not know who omitted steps. The simplest solution to continue the experiment was to start it over.

The case of Subjects 3 & 4 showed that working in pairs helped the subject who was late. Subject 4 not only caught up the time she missed in learning the PSL, but also was able to give Subject 3 some suggestions to solve a mechanical problem. Her performance in level two experiments demonstrated that she was able to use the PSL very well. On the contrary, the case of Subjects 11 & 12 did not show that working in pairs helped Subject 12 catch up on the information she missed because she was late.

Subject 12 watched Subject 11 worked for a short time, then left without saying anything.

One question is raised in this study, "What kind of situations seemed to make collaboration work better?

In this study, pairs 3 &4, 7 &8, 9 & 10, 19 & 20 seemed to work better then pairs 5 & 6, 11&12, 13 & 14, 15 & 16, 17 &18. These two groups had the following differences:

• Pairs 3 &4, 7 & 8, 9 & 10, 19 & 20 at least had computer experience in word processing (except Subject 7). In pairs 5 & 6, 11&12, 13 & 14, 15 & 16, 17 &18, only Subjects 11, 13 and 14 had computer experiences in word processing. The others only had experiences in computer games. (See Table 4-11 for further information) It seems that the more computer experiences the subjects had, the better they cooperated.

• Pairs 3 &4, 9 & 10, 19 & 20 stated that they had worked together. Subjects 7 & 8 said that this study was the first time they worked together, however, both of them thought aloud and talked a lot. Pairs 5 & 6, 11&12, 13 & 14, 15 & 16, 17 &18 stated that the first time they worked together was in this study. They seldom talked or did not talk at all. It seems that pairs who had worked together and thought aloud cooperated better.

The following table shows their collaboration and their grade levels.

Table 4-17 Collaboration vs. grade levels

Subjects worked in pairs	Year in school	Collaboration
Subjects 3 & 4	11	Better
Subjects 5 & 6	8	
Subjects 7 & 8	8	Better
Subjects 9 & 10	8	Better
Subjects 11 & 12	7	
Subjects 13 & 14	7	
Subjects 15 & 16	7	
Subjects 17 & 18	7	
Subjects 19 & 20	7	Better

At grade eleven, one of one pairs (100%) collaborated better.

At grade eight, two of three pairs (67%) collaborated better.

At grade seven, one of five pairs (20%) collaborated better.

It seemed that subjects who were at higher grade levels collaborated better.

Finding 8: In this study, some evidence showed that the PSL provided an environment for 4 pairs of subjects (45%) to share their ideas to solve mechanical problems, raise question about the data, initiate discussion about the data and supplement their prior knowledge to understand the experimental results. For 5 other pairs of subjects (55%), there seemed to be no advantages. It seems that partners who had more experiences, thought aloud, talked and cooperated better. It also seems that the higher subjects' education level, the more possibility they cooperated better.

Research Foci Nine: Does PSL improve the computer readiness of a teacher?

The researcher tried very hard to invite more teachers to participate in this study, but only one teacher participated. Computer readiness here means a teacher was able to transfer his/her prior computer experience to the PSL environment and was able to learn more as the need arose.

Subject 23 (level one and two experiment)

Subject 23 was a social science teacher in an elementary school. He had experience in using a word processing program on a Macintosh computer, but had never used IBM computers. By following the instructions, he successfully completed the three activities in level one. When he calibrated the temperature probe, he forgot to press the Enter key. In order to eliminate those small pop-out windows, he pressed the Enter key first, but the Enter key did not work in this situation. Then he read the instruction and tried the Escape key to eliminate the small pop-up window. After several times, he discovered that the Enter key and Escape key were very important when using IBM computers and their functions.

Subject 23 was very interested in the "real-time" computer graphs. When he did experiments with the temperature probe, he made a temperature graph as follows.

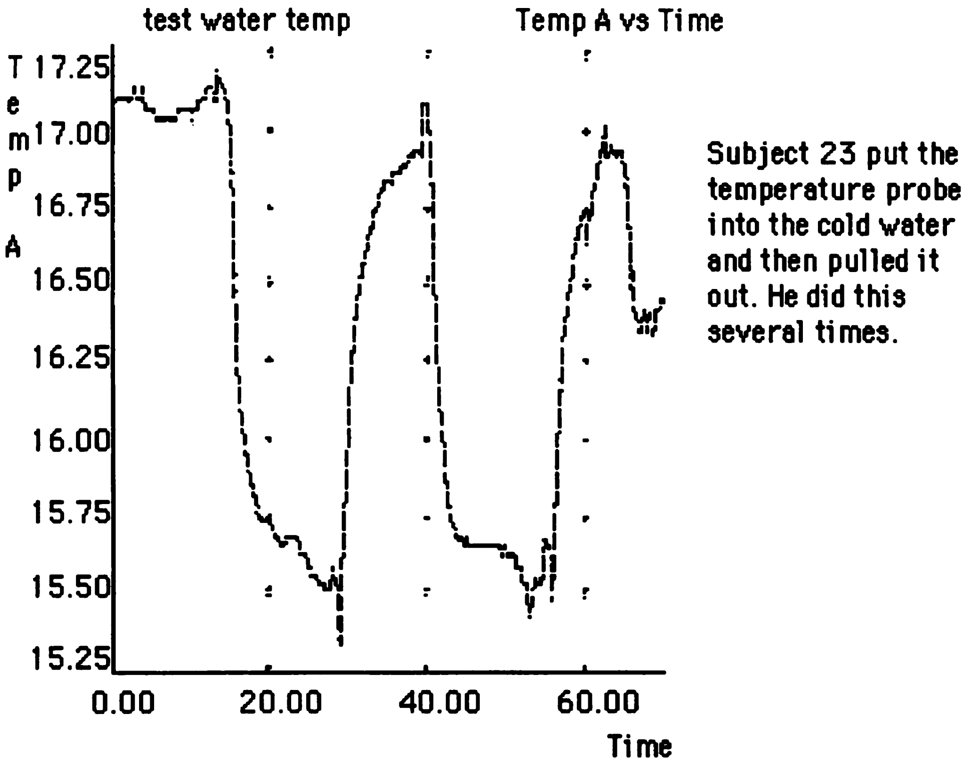


Figure 4-42

Subject 23 understood all the graphs in the temperature experiments, but he could not figure out why the following upper graph was flat when he was doing the simple pendulum experiment.

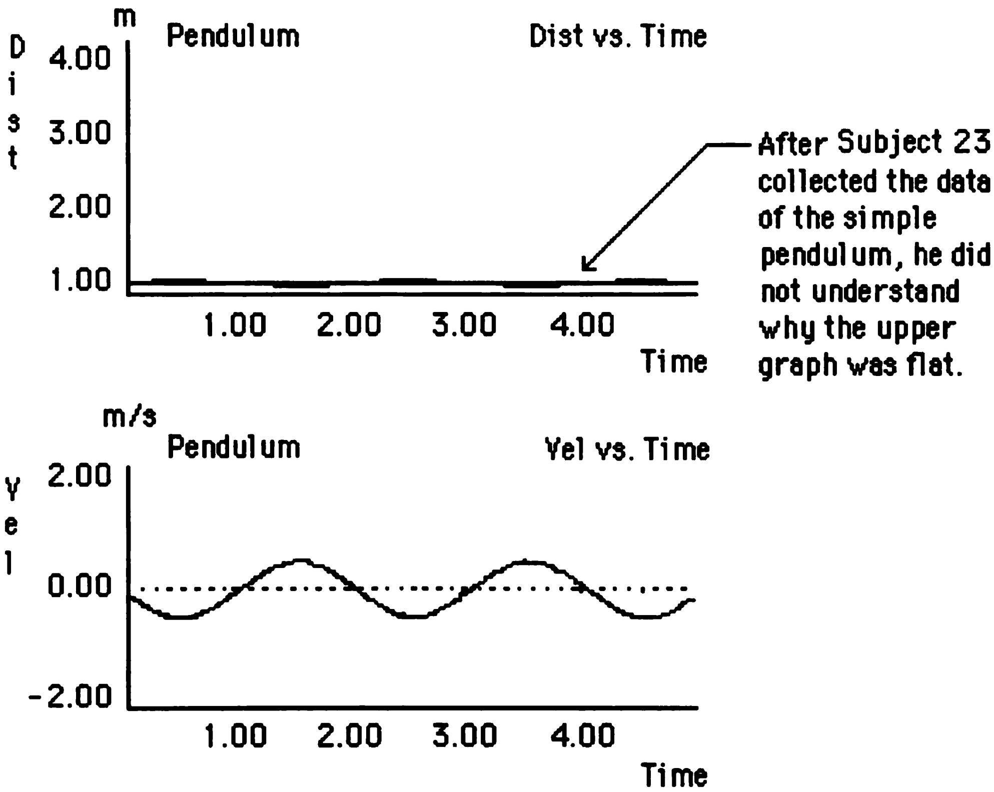


Figure 4-43

He read the PSL manual again and used the scale key to rescale these graphs. Then he repeated the experiment, he realized the numbers on the axis changed when he rescaled. From this procedure, he understood what "scale" meant and why the above upper graph was flat.

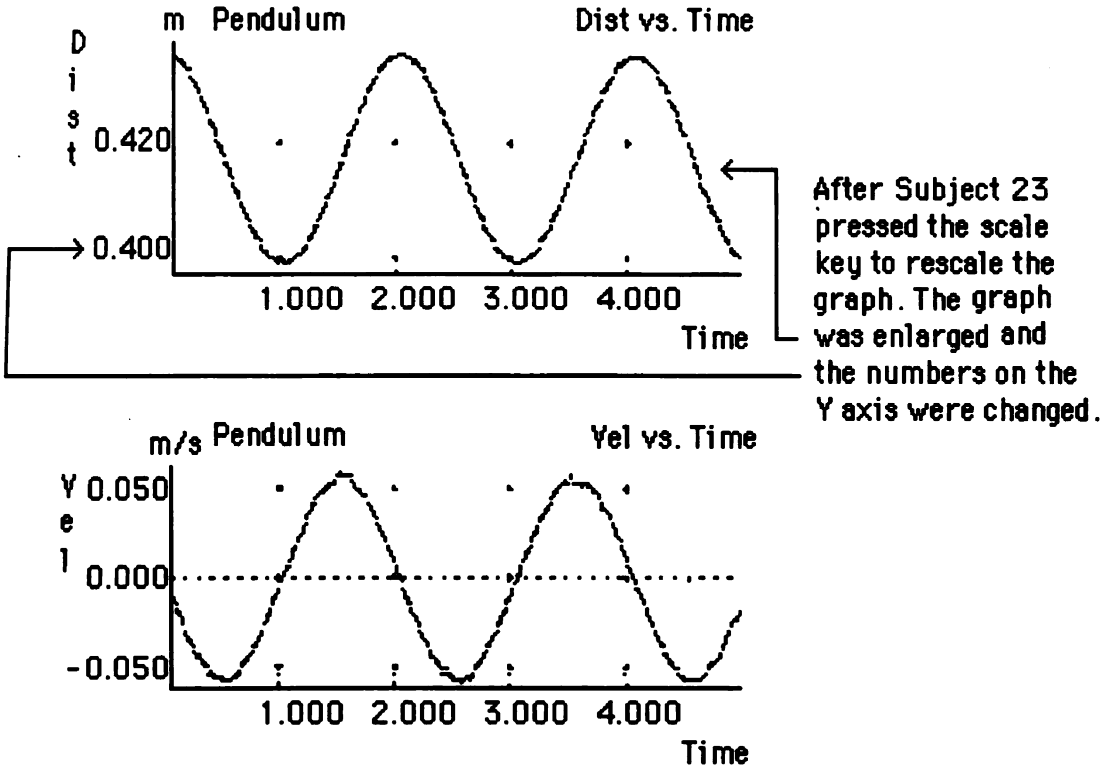


Figure 4-44 Simple Pendulum (after scale)

As a matter of fact, the PSL helped him make progress in reading graphs. He told the researcher that the numbers did not make sense to elementary school students, but elementary students would be able to understand computer graphs.

After the experiments, he wanted to try an IBM word processing program. He explored MS WORKS for a while and found that the ideas of MS WORKS and PSL were very similar. He realized that ALT and TAB keys play an important role in MS WORKS. He seemed proud of what he did and he said he could use the IBM computer comfortably. He said the PSL helped him learn how to use an IBM computer.

Discussion:

Subject 23 had computer experience on Macintosh computers, but did not have experience on IBM compatible computers. Sometimes he used the experience he had on the Macintosh platform to solve problems he faced in PSL, but it did not always work. Fortunately, the PSL allowed him to repeat the procedure again and again. The repetition helped him discover some differences between Macintosh computers and IBM computers; it helped him transfer his experience from Macintosh to the IBM.

Repetition seems to be a good way for the people to discover something. The computer-based programs provided the kind of environment that helped users to learn something by themselves. In addition, the immediate feedback helped him understand some terminologies of the PSL, such as, Scale.

Since only one teacher participated in this study, this finding is very tenuous.

Finding 9: Subject 23's case showed that the PSL helped him learn how to use an IBM computer to collect experimental data and use the scale key to examine the graphs for details. It seemed that the PSLs capability of allowing users to repeat experiments very fast helped him understand the experimental data and learn some terminologies such as Scale.

Chapter Summary

The nine research questions related to the impact of the PSL on learning physics were investigated by this study. The data were presented through nine research questions. The findings in this study showed that the PSL had a positive impact on learning physics. This study also disclosed some areas which needed further research. A summary of the study, implications, conclusions and recommendations are included in Chapter V.

CHAPTER V

SUMMARY, FINDINGS AND RECOMMENDATIONS

This chapter summarizes the results of the three level procedures and the findings of the research questions. Based on these summaries, various recommendations are stated.

Summary of the Results of the Three Level Procedures

The subjects' activities were observed at three levels. They were: 1) learning how to use the PSL program, 2) applying the PSL program and 3) promoting creativity for the usage of the PSL. Creativity here is defined as the process whereby subjects were able to combine parts to form a unique or novel solution to a problem.

It is important to note that without teacher training, this technology won't be used.

Table 5-1 Summary of the Results of the Three Level Procedures:

	Using PSL
First Level: Learning how to use the PSL program. The subjects' approaches were very similar.	Subjects learned how to use the PSL program: Every one followed the step-by-step procedures to perform the experiments. All of the subjects successfully completed three experiments. However, they understood the results in different degrees of sophistication.
Second Level: Promoting application using the PSL program. The subjects' approaches were different in some methods.	Subjects used the PSL program to: Design their own experiments with different set-ups; investigate the experimental data in different ways and understand the experiment results in various depths.
Third Level: Promoting creativity using the PSL program. The subjects' interests and approaches were very different.	Subjects combined parts within the PSL or combined another program, such as MS WORKS to form a unique or novel solution to a problem. Their performances reflected the depth of thinking.

In this study, all the subjects completed the first level of learning to use the PSL program successfully and appeared to enjoy using it. In the first level, there did not seem to be much difference between subjects' performance in following the step-by-step procedures to complete the three temperature experiments. However, their prior knowledge of physics played an important role in determining their ability to explain and / or understand the experiment. For example, in the temperature experiment, almost all subjects realized the difference between blowing on a temperature probe and blowing on their skins. Subjects who had no physics, however, were not able to explain the reason for this difference. Subjects who had a physics background were able to explain the difference logically.

It was interesting to note that subjects who had prior science knowledge were eager to try the higher level two experiments. Subjects who did not have prior science knowledge quit the experiment after level one.

In the second level, prior subject matter knowledge was even more significant. Subjects who had subject-matter knowledge concerning physics or mathematics were able to design an experimental set-up in different ways and analyze the data with greater depth and in more detail. For example, the two experimental set-ups designed by subjects which related to the pH value and temperature experiment differed. Perhaps this was because the eleventh grade subject understood Function (i.e. A function f from a set X to a set Y is a correspondence that assigns to each element x of X a unique element y of Y.) and the subject of ninth grade did not understand this concept. Another example, a subject who had physics background discovered a more accurate way to measure the period of the simple pendulum. As a result, this subject investigated the problem in more depth than those subjects who had no physics background.

In the third level, subjects' interests differed greatly. Some were able to combine parts of capabilities within the PSL program to form a novel solution. Other subjects were able to combine MS Works with the PSL to form more novel solutions to a problem. Their creativity reflected their computer experience, their subject-matter knowledge and their desire to experiment with new ideas. For example, a subject who had background in mechanical engineering was interested in finding equations to represent the data obtained from the experiments. A subject who had a mathematics and computer science background was more interested in using calculations. However, both of them were able to combine different capabilities of the PSL program to solve the problems.

Findings from the Research Questions

The PSL program provided a new environment for scientific experiments. Its sampling rate was very high, 34 times per second for the motion probe and 87 times per second for the pH probe. Its measurements of distance and temperature were very accurate (i.e. 0.50 millimeter for the motion probe, 0.05 degree of Celsius for the temperature probe). After the subjects' experiments, the PSL automatically stored the data in the computer and allowed subjects to analyze it graphically or by using the calculation commands that the PSL program provided. In addition, the subjects discovered that they could exchange data with MS WORKS.

The findings of this study indicated that the PSL program laid the foundation for an excellent learning environment. It had the following positive aspects that could enhance physics education.

1) The PSL enhanced subjects' abilities to discover some challenging phenomena with the use of computer graphs that were not available in the traditional classroom lecture or experiments. For example, all subjects discovered the difference between blowing on the skin and blowing on the temperature probe. This difference was so minimal and occurred so quickly that students would not likely to detect this phenomena by using a regular thermometer. However, this conflict engaged 30% of the subjects to think about "why the temperature seemed to be different between the skin and the probe", 10% of them formulated hypotheses for further investigation. One high school subject who had a physics background discovered the time difference between two adjacent peaks. Her discovery could not be found by using a regular stop watch.

2) The PSLs capability of integrating science, mathematics and computer technology allowed subjects to repeat experiments several times

during a lab hour. Subjects utilized these capabilities to practice some professional research skills. For instance, all subjects of pendulum experiment discovered that, by repeating the pendulum experiment using different lengths, the longer that the pendulum extend, the longer its period. One high school subject who had a physics background even formulated two hypotheses and tested them.

3) Subjects who had strong subject-matter background with a strong computer experience could perform some complex approximations that they would not have been able to do in a traditional physics class. For example, the engineering graduate student completed four complex approximations for the experiments. His college course in physics did not make this possible.

4) The immediate feedback, the reverse operations and the data presented in both graphs and tabular forms provided a means for some subjects from middle school and high school to understand the calculation process. For example, the middle school and high school subjects understood ADD A CONSTANT and SUBTRACT A CONSTANT by applying ADD 2 and SUBTRACT 2 to the graphs.

5) The PSL provided understandable computer graphs for the subjects. It enhanced their abilities to view the experiment results from various perspectives. For example, subjects viewed the experimental results by telling about how and how fast each phenomena happened. They were able to establish physical relationships from graphs. However, subject-matter knowledge was needed in order to read some computer graphs. The spring constant K in Figure 4-25 and Figure 4-26 demonstrates the need for subject-matter knowledge to better understand its concept.

6) The PSL was a user friendly program. Subjects from middle school to graduate level were able to use it. The graduate students even stated that it was sophisticated enough to use for research. It provided an opportunity for subjects at different levels to become successful in physics education. In this regard, the PSL promoted motivation for subjects at different learning levels. For example, all subjects from seventh grade to the graduate level were able to learn how to use the PSL on their own and use it to perform the level one experiments.

7) The PSL provided an arena for students who had more computer experience and more subject-matter background to explore the experiments in greater depth. For example, an engineering subject completed several complex approximations which he was not able to do when he took physics in college.

8) The PSL supported and encouraged collaborative learning for some subjects. For example, subjects who worked together demonstrated many benefits in solving mechanical problems and understanding the experimental results.

Discussion

This section discusses the research findings by comparing them with those found by authors such as, Ronald K Thornton and David R. Sokoloff. The major foci of their article was to investigate how effective the MBL was in teaching kinematics. Based on their research, Thornton and Sokoloff concluded,

> We believe that the following five characteristics of the MBL learning environment-made possible by the tools, the curriculum, and the social and physical setting--are primarily responsible for the learning gains.
>
> 1) Students focus on the physical world.
>
> 2) Immediate feedback is available.

3) Collaboration is encouraged.

4) Powerful tools reduce unnecessary drudgery.

5) Students understand the specific and familiar before moving to the more general and abstract. (Thornton & Sokoloff, 1990)

The following comparison of the PSL program with the five characteristics of the MBL which Thornton & Sokoloff concluded are that:

The comparison showed that subjects focused on the physical world while they performed experiments with the PSL. For example, when subjects blew on the temperature probe and their skin, about 30% of the subjects noticed the difference and asked why. Some subjects formulated assumptions to explained the discrepancy.

In the temperature experiment, when subjects touched the temperature probe, the computer graphs moved upward. Subjects understood that "moved up" on the computer graphs corresponded to "temperature increase" in the temperature experiment. In the simple temperature experiment, when subjects saw the pendulum move far away from the motion probe and the indicator of the distance on the computer graph move up, they understood that "move up" on the computer graph corresponded to "far away" for the pendulum swing.

In this study, there was evidence of collaboration that certain attributes of the PSL (i.e. understandable graphs and immediate feedback) seemed to encourage for some subjects who worked together. However, some subjects who worked in pairs did not show evidence of collaboration. The difference was probably due to the following facts: 1) Subjects in Thornton and Sokoloff's research project were students who were enrolled in the introductory physics class, they had the same interests--physics and therefore had more in common. Subjects who collaborated in pairs in this study were not enrolled in a physics class. Some stated that they were interested in the PSL program itself and some stated that they were interested in scientific experiments which the PSL initiated. 2) In Thornton and Sokoloff's project, research was conducted in a regular introductory physics class and subjects were divided into groups of two to four in the same physics class. However, subjects were not divided into groups in this study (They were scheduled based on the time that was convenient for them). If a subject came individually, he/she worked individually. If subjects came with someone, they worked together in pairs. Some subjects who worked together were from the same grade, but were not necessarily from the same classroom. Some of them were not acquainted. 3) Thornton and Sokoloff's research project used a common curricula and their research focused on a specific topic--the kinematics curriculum. For example, in the velocity section of "Introduction to Motion", investigation one contained a number of exercises using distance graphs. Students were asked to graph their velocities as they walked quickly and slowly toward and away from the motion detector. They were then asked questions about the graph's representations of fast, slow, away from, and toward. (Thornton & Sokoloff, 1990). This PSL study did not use any specific subject-matter curriculum to guide subjects' investigation because learning specific subject-matter knowledge was not the focus of this study. 4) Thornton and Sokoloff's research project was a long-term research project. For the amount of time that the students used the MBL to investigate the kinematics graphs, they probably would have known how to use the MBL very well. However, subjects in this PSL study were first time users of the PSL program. In the level one experiment, they learned how to use the PSL program while performing temperature experiments. Some subjects learned the PSL quickly while others learned more slowly. Based on these facts, this author assumes that subjects in Thornton and Sokoloff's research project had more in common than subjects in this study. Yelu Yu's educational communication model could be applied to explain the differences between Thornton and Sokoloff's findings and this researcher's findings. (See Figure 1-1 in Chapter one for further information) In this situation, the communications were between two subjects.

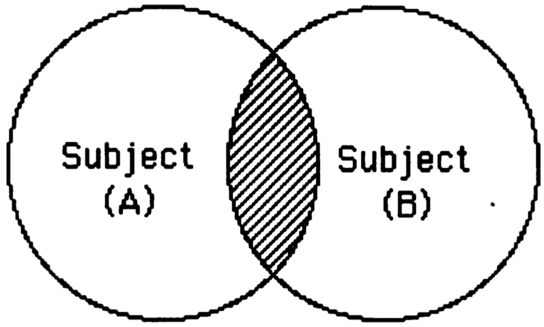


Figure 5-1 Subject A-subject B collaborative learning

In Thornton and Sokoloff's research project, subjects were enrolled in the same physics class and the research was conducted for one semester or for one year. The MBL's kinematics curriculum was incorporated into the subjects' physics class. As a result, subjects had more common knowledge and experience and therefore collaborated with each other more freely.

The understandable graphs and the immediate feedback seemed to encourage collaboration for some subjects in this PSL study. However, other subjects who worked in pairs did not collaborate or at least did not seem to. Perhaps, it was due to the fact that the overlapped portion of their common knowledge and experiences was minimal. If a teacher were present and helped them to open up some channels of communication by pertinent questions and guidance, the subjects who did not talk might have responded orally. This would have increased collaboration.

The results of this study supported Thornton and Sokoloff's conclusion that, "Powerful tools reduce unnecessary drudgery." For example, the PSL helped subjects save time in collecting, recording and analyzing data.

The results of this PSL study also supported Thornton and Sokoloff's conclusion that, "Students understand the specific and familiar before moving to the general and abstract." For example, in the simple pendulum experiment, subjects understood that the pendulum moved back and forth and that each swing took almost the same amount of time. As they continued to experiment with different pendulum lengths, they further understood that each swing also took almost the same amount of time. In addition, subjects further realized that the time interval of each swing related to the length of a pendulum. This progression helped subjects move to the more general and abstract concepts or principles.

Therefore, the results of this PSL study agree with Thornton and Sokoloff's conclusions. However, since the subjects' backgrounds differed, the foci of the researchers and the research methods differed. This PSL study made some new findings. These new findings were:

1) The high sampling rate and the accurate measurement of the PSL program created challenging phenomena for students from seventh grade to the graduate level in a very simple temperature experiment. The experiment was simple, but the phenomena was challenging. This implied that with the help of the PSL program, the same traditional experiment could include some phenomena that students and / or teachers had never seen before.

2) The PSL program has potential capabilities that could assist students in practicing some very professional research skills.

3) The PSL program provides new tools for students to do approximations which they would not able to do using traditional methods.

4) Middle school and high school students could take advantage of the PSLs capabilities, such as immediate feedback, reverse operations and data presented in both graphical and tabular forms, in order to understand the internal calculation process.

5) The PSL computer graphs assists students to understand the experimental results from different perspectives.

6) The previous researches found that students from the sixth grade to the college level were able to use the PSL. This study also invited graduate students to participate. They used the PSL as an opportunity to learn more in-depth physics. Their accomplishments in the PSL experiments caused them to believe that the PSL would be an

exciting intellectual challenge, particularly when they discovered some phenomena which needed further investigation. Thus, their motivation to learn more about the PSL increased and lead them to complete some complex approximations.

7) Previous research had found that the PSL supported and encouraged collaborative learning. However, this study showed that collaborative learning was evident in 45% of the groups who worked in pairs.

Recommendations for Further Research

This study employed the PSL program's concepts in order to investigate the impact that the MBL environment could have on subjects who were learning physics. The results of this study showed that the PSL program had a positive impact on subjects' learning of physics.

This study also disclosed some areas that needed further research.

Further Research 1: In the simple temperature experiments, the experiments were simple, but the questions raised from the experiments were not simple. For example, 1) Subjects who blew on the temperature probe and blew on their skin found that the temperature increased on the probe and their skin felt cool. This phenomena challenged many of the subjects to think critically. 2) Two subjects placed two temperature probes in a water container and found that the two temperature probes indicated two different temperatures. They were questioned why this happened. 3) Some subjects found that the room temperature in the lab was lower than the cold water from the cold water faucet. This initiated some more important questions dealing with what the role the teacher might play in physics education:

- If a teacher were present and provided some guidances to assist students, would it be possible for students in various grade level to discover the cause of an effect and learn something new about heat and temperature?
- If some new phenomena of physics challenges not only students but also the teacher, and the teacher is not able to find a logical explanation, what will happen? Will this discovery encourage or discourage teachers using the PSL?

Further Research 2: The PSL environment allowed students to collect and analyze data quickly so that students were able to repeat the experiments several times in the amount of time designated for a lab. The results of this study showed that some subjects could explore, analyze, formulate hypotheses and test them in the time allotted. This implies that the PSL program could be used to create a learning environment that students could use to explore, analyze and build their own theories.

- Would students receive more experience in research skills and critical thinking if a new approach (i.e. students explore, analyze and build their own theories by using the PSL) is employed?

This question may seem very general. This author constructed the following specific example in order to clarify this idea. It illustrates the possibility of conducting this further research.

In this PSL study, subjects recalled that the simple pendulum experiment gave the opportunity to investigate a theory they had not studied previously. Based on the accurate data that the subjects collected, they were able to formulate two hypotheses and discover new ways to measure the pendulum period very accurately with the help of the PSL analysis tools. Their performance and results led this author to formulate a new approach for students to learn the theory of the simple pendulum through the PSL environment.

Briefly description of this new approach:
Traditionally, high school students usually learned the basic theory of the pendulum from the textbook first and perform simple experiments to test the theory later. In the PSL environment, students may learn the pendulum through exploring, analyzing and building on a theory that they generate. The research question for this example is, "Can students, with proper guidance and experiment, discover mathematical relationships among various variables such as, period (T), length (L) and the acceleration due to gravity (G)?

Specific procedures for this research are:

1. Students collect pertinent data for the simple pendulum by using the PSL, then save the data for later use.
2. Students measure the variables of the period T, amplitude A; and customize the wave so that the initial phase of the wave is zero. They then export the data to a spreadsheet and apply a formula to create a new set of data which

represents the real-time experiment data. Write down this equation.

Some specific questions are raised for further research here:

- Will high school students be able to find an equation to represent the pendulum wave they obtained from experimentation?
- If they are able to find the equation to represent the data they obtained, will they be able to explain how well the equation represents the data?
- What types of research skills would students obtain in this kind of approach?

Further Research 3: In this PSL study, a middle school subject explored the Fit-line equation. The computer's immediate feedback seemed to make a great deal of sense to him. It is often very difficult for a middle school student to understand the theory of the Fit-line equation. However, this example suggested that it is possible for a middle school student to apply this tool in order to analyze the experimental data in the PSL environment, if appropriate guidance and assistance are provided. One question is raised:

- Would students be able to learn mathematics and science (e.g. Fit-line equation) at an earlier age than was ever thought possible, if the PSL environment were used?

Further Research 4: A graduate student who had both physics subject-matter and computer background used the PSL very well; he completed four approximation experiments. This was the first time the subject had used the PSL. This implied that the subject was able to transfer prior knowledge which was learned from the traditional approach to the PSL environment.

This raises another question by this author:

- Would a student be able to transfer the knowledge he / she learned from the PSL environment to a new situation (For example, solving problems in the traditional textbook)?

This research question seems too general. A specific example to pursue this research is recommended by this author:

The ideal graphs of Velocity vs. Time and Acceleration vs. Time of the uniformly accelerated motion in two dimension are straight lines. These led this author to formulate the following experiment set-up to help high school students learn Newton's Second Law through the PSL environment.

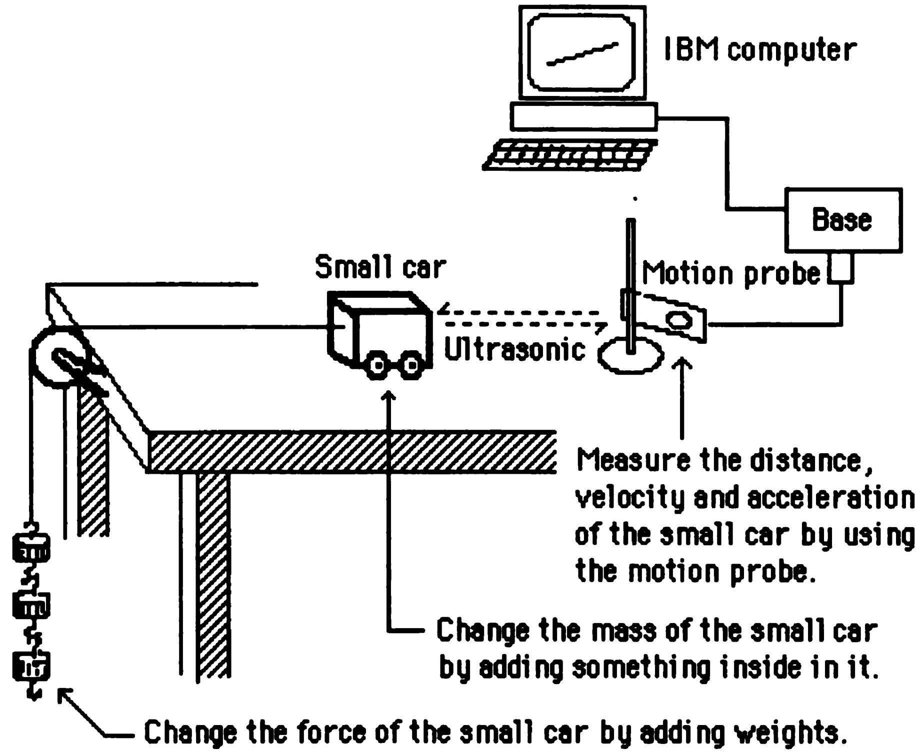


Figure 5-2 Exploring Newton's Second Law by using the PSL

This experimental set-up employs the motion probe to measure the distance, velocity and acceleration of the small car. A student might change the weights or the mass of an object in order to explore the relationship between force and acceleration. After collecting the data, students could use the Reset Parameters command to construct graphs of Distance vs. Time, Velocity vs. Time and Acceleration vs. Time. Finally, students could use the Fit-line function to discover equations for Velocity vs. Time and Acceleration vs. Time. Some questions derived from this suggested experiment for further research are:

- Does success on a computer-based experiment indicate that a student has fully understood the concepts of force, mass and acceleration and the reasoning (i.e. finding the relationships of force, mass and acceleration) has involved?
- Does practice in learning basic physics concepts and principles promote the development of scientific reasoning ability, so that a student can reason successfully about new situations (e.g. solving problems about Newton's Second Law in the traditional textbook theoretically by applying the concepts they learned from the PSL experiments)?

Further Research 5: The question that follows emphasizes the connection between math and the real world phenomenon. This outcome of the question could enhance math learning considerably.

One student raised an opinion which was very perceptive. This subject stated: "The PSL can be used to teach mathematics." The comment was based on the fact that the calculation process was understood by dealing with the calculation commands contained in the PSL capabilities. These capabilities were: immediate feedback, interaction, reverse operation and data presented in two forms, i.e. computer graphs and tabular forms. This author recommends that the PSL be used to assist students to learn: 1) Logarithmic functions through the heating curves, 2) Concepts of derivative and integration through the relationships among distance, velocity and acceleration. 3) Graphs of the trigonometric function through the graphs of the simple harmonic motion.

Jack M. Wilson succinctly stated that:

> Selection of topics and indeed the physics sequence itself are largely determined by the expected mathematical level of the student. At the high school level, students are generally expected to know trigonometry. In the introductory university physics sequence, students are expected to start with a little knowledge of calculus and develop more proficiency as they advance through the sequence. (Wilson, 1990 p, 46)

In this study, there were participants who had taken introductory analysis and others who had only completed pre-algebra. This meant that even though the subjects were in the same grade, their mathematical levels differed considerately. This would naturally influence the way they approached a physics experiment. Some of the subjects in the same physics class in high school had very different mathematical backgrounds. Some questions are raised here for further study.

- Could the PSL be used to teach mathematics?
- If the PSL could be used to teach mathematics, could the PSL be used to bridge the gap between the abstract mathematical concepts and the concrete physical application?
- Could the PSL be used to eliminate some learning barriers for students who had not taken the related mathematics class and enable them to understand physics?

Further Research 6: The results of this study indicated that middle school and high school subjects read the calculation changes from the table better than reading the changes from the graphs (See research question four). The results of this study also showed that the PSL presented data in an understandable form; it helped students to understand the subject-matter through different perspectives (See research question five). The facts were: The computer graphs that middle school and high school students obtained in this PSL study were Temperature vs. Time, Distance vs. Time and pH vs. Time. When they collected the data, they saw the temperature, distance and pH value change on the computer screen. The changing process of the experiment helped the subjects understand the computer graphs. However, when they applied a calculation command to the computer graphs, they were not able to see the changing process because the calculation worked behind the scene. Therefore, it took considerable time for subjects to understand the changes. Some problems remain for further research:

- If a graph did not include time as a horizontal coordinate (X-axis), for example, pH vs. Temperature or Intensity of light vs. Distance, is it possible for middle school and high school students to read and understand them easily?
- Further more, if a high school student chose Distance vs. Velocity experiment set-up to perform a simple pendulum experiment, will this student understand the graphs of Velocity vs. Time?
- Will a student understand the graphs of Acceleration vs. Time?

- How can the PSL be used better in order to help students understand more complex and more abstract graphs?
- Does the student's ability to read the graphs relate to their subject-matter knowledge?

Further Research 7: The results of this study indicated that students in level one were not required to know anything about computer usage in order to use the PSL. However, students did better in level two and level three, if they had some prior computer experience. Questions that need further research are:

- Should a physics teacher also teach computer skills in order to help students perform more complex physics tasks?
- Should teaching of computer skills become part of the physics curriculum?
- What level of computer skills are needed for physics students?

Further Research 8: Thornton and Sokoloff's research project showed that the MBL encouraged collaborative learning in the regular physics classes for the college level students. The results of this study's observation indicated that some students who worked together gained several benefits. These implied that the MBL could be used to created an environment for students to learn science through more project-oriented approaches. In the projected-oriented approach, students are arranged in groups and are directed to collect data, discuss the experimental results and investigate challenging phenomena.

These questions therefore arise:

- Will students become more active in learning physics by using the projected-oriented approach in the MBL environment?
- Will the MBL learning environment encourage students who are weak in physics to receive help from students who are stronger?
- Will peer discussion help students understand the basic concepts and rules in more depth?
- Science research often needs teamwork. Will students get training for teamwork through the projected-oriented approach?

Further Research 9: In the traditional physics education, "Even successful physics students who can solve all of the problems at the end of the chapter generally lack physical intuition."...(Thornton, 1987 p. 231) "In fact, laboratories are often omitted from or de-emphasized in course because many laboratory instruments are hard to use, fragile, unreliable and expensive. In addition, the teaching laboratory is not thought to be a place where students can learn physics but a place for developing laboratory skills, which are of limited academic usefulness."...(Thornton, 1987 p. 231) "Laboratories of this sort are better omitted from courses because they discourage students, provide no new information about nature and given an incorrect view of the process of science." (Thornton, 1987 p. 231)

The results of this study, suggested that the PSL has the potential capability to bridge the gap between theoretical prediction and scientific experiment. In order to investigate this capability further, this author recommends the following experiment:

A dilemma facing the coffee drinker is to decide whether it is better to add the cool cream to the hot coffee, stir, and let it cool down, or to let the black coffee cool down first and then add the cream.

To solve this dilemma theoretically involves making many assumptions based on Newton's Law of cooling and the method of mixture. Finally, it involves solving a differential equation. (Greenslade, 1994)

Two scientific approaches could be applied to solve this problem, one is deductive reasoning (from general to particular) and the other is inductive reasoning (from particular to the general). To solve the coffee cooling dilemma, Greenslade applied deduction. It is difficult for a high school student to explore this daily life problem in this way because his / her limited mathematics background. With the help of the PSL, it would be possible for a high school student to discover the answer to this dilemma. By using Two-Temperature-Probe experiment set-up they could compare which way the coffee cools down faster. The questions raised for further research are:

- Will the real-time data of the PSL match Greenslade's theoretical prediction?
- If the PSL experimental results do not match Greenslade's theoretical prediction, how might middle school students explain it? Do students believe Greenslade's theoretical prediction or their own experimental data?
- Is it possible that the use of computer-based experiments to learn science might encourage routine application of experimental data without enhancing ones understanding?
- When students attempt to follow prescribed procedures, will they think of the physics involved or will their attention be devoted mostly to recalling and following directions?
- Could the PSL bridge the gap between theoretical prediction and scientific experiment?

Further Research 10: **The** book Conceptual physics has been used in high school for several years; this book allows students who do not have a good mathematical background to learn physics. However, with the help of the PSL, students would be able to obtain a great deal of quantitative data. Knowing only the basic concepts of physics is not sufficient for students to obtain more knowledge by using the PSL. The current physics curriculum needs to be changed in order to meet the needs of different levels of knowledge of students.

- What changes are needed?

Further Research 11: The findings of this study indicated that the ways subjects used the PSL were related to their prior knowledge in science and computing. That prior knowledge also helped them get the most out of the PSL. Several research questions are raised in this context:

- Since seventh grade students were able to use the PSL very successfully in this study and sixth graders were able to use the MBL in the previous research, what is the minimum grade level at which students can use the MBL successfully?
- In this study, a ten-minute video (See Appendix A) was effective in teaching subjects how to use the PSL. If students lack prior knowledge, can they still use the PSL package successfully with a tutorial program substituting for a teacher's help? What additional training materials should be prepared to provide this kind of help?
- How can technology like the PSL and subject matter be interwoven to provide needed prior knowledge to improve curricula?
- In this study, this author had some opportunities to contact some science teachers (Note: they were not subjects in this study) informally in both middle school and high school. They stated that they were interested in the MBL, but felt that they needed training to keep up with the technology. For example, a physics teacher had a PASCO's Science Workshop (one version of the MBL) for several years, but used only very simple applications in his physics class. He

said he did not have enough time to learn the new technology. Do teachers need special training to providing necessary prior knowledge to enable to students use the MBL?

It seems as though there are many areas that need further research in order to use the MBL environment more effectively and more efficiently in physics education.

Suggestions for Improving Physics Education with the PSL

The results of this study showed that the PSL program is an excellent tool for learning physics.

1) The PSL could be used to demonstrate some challenging phenomena which students could not see without using the PSL. This study provided two phenomena to show this PSLs capability: one was the difference between blowing on skin and blowing on temperature probe. Another was the different time intervals between two adjacent peaks of a pendulum. In his article, "Tool for Scientific Thinking---Microcomputer-Based Laboratories for Physics Teaching", Ronald Thornton stated that, "Such instruments not only extend the kinds of phenomena that can be investigated, they also measure phenomena over time-scales that are both shorter and longer than can ordinarily be conveniently used. Temperature variations can be measured over days to study diurnal temperature cycles and weather changes, while sound pressure waves are easily measured and displayed over milliseconds." (Thornton, 1987)

2) With the combination of MS WORKS spreadsheets, the PSL could be used to compare the scientific experiment data with the theoretical prediction. This is because the PSL allows students to collect real-time experimental data, store data in a computer for later analysis and exchange data with spreadsheet programs. (See research questions 3 & 4 in Chapter four for more details) On the other hand, spreadsheets allows students to input formulas easily in order to experiment with theoretical simulations. (See the

role of computer simulation in physics education in Chapter two for details) The approximations that the engineering graduate student completed demonstrated this PSL capability.

3) Some guidance materials could be developed in order to assist and encourage students to do further investigation for depth in the PSL experiments. The challenging phenomena that the simple temperature experiment created in this study suggested this need. Thornton & Sokoloff's research findings (1990) also showed that the MBL tools were not enough, the combination of the tools and the appropriate curriculum materials were needed.

Concluding Thoughts

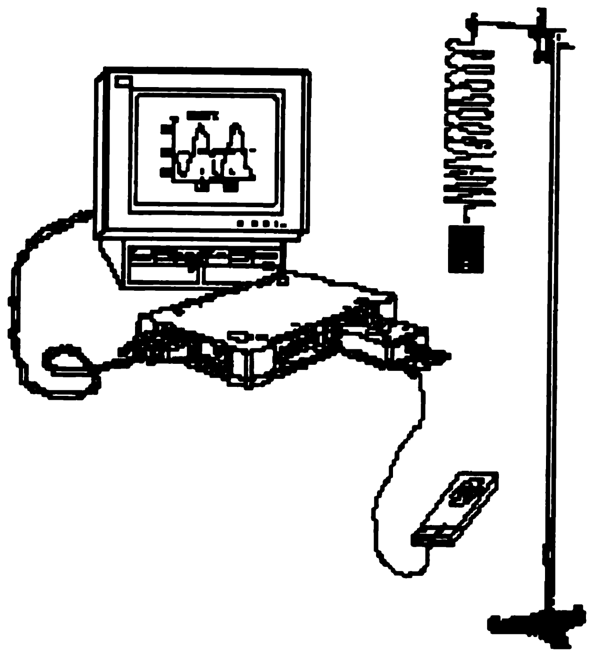
The MBL opens up a new arena for physics education. In this study, the more this researcher observed students using the PSL, the more possibilities of using the PSL program derived. This study also suggested several areas that needed further research. This author believe that the PSL will play an important role in physics education.

Finally, this author would like to use the word processing program as an analogy to predict the future for the MBL. The word processing program is not a teacher of writing for this author. However, the word processing program helped this author edit text faster, easier, and more accurately so that he did not have to be concerned about spelling and grammar errors because he could make changes at any time. This author used these capability to focus on how to better organize ideas and data. This author found the word processor to be an excellent tool. Elementary school students are able to use it in their writing classes; the university professor can use it to create materials for teaching and for research reports. The MBL is not a subject-matter teacher, but it certainly could help students do experiments and research faster, easier and, perhaps, it would promote more in-depth learning. This author believes that middle school students would be able to use the MBL for learning physical science, while graduate students would probably like to use it for learning physics and doing research in the future.

APPENDICES

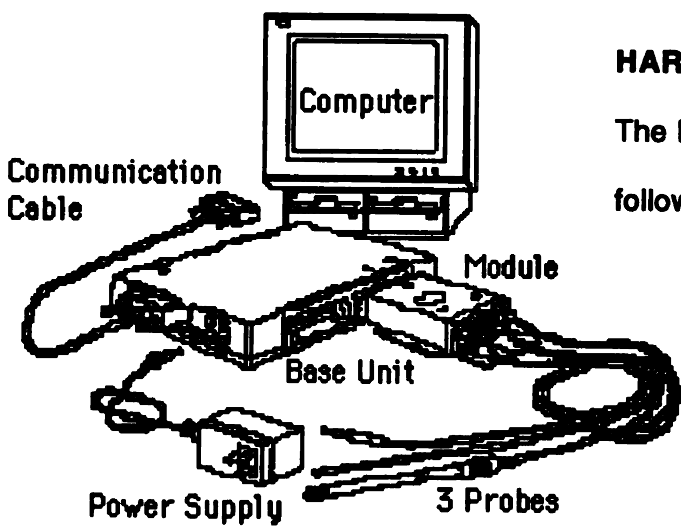
APPENDIX A

The Storyboard of Introductory Video of the PSL



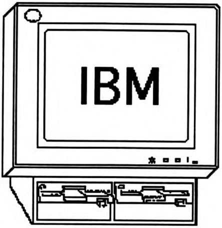
INTRODUCTION

The IBM Personal Science Laboratory (PSL) is a flexible and powerful microcomputer-based laboratory. PSL consists of hardware and software, which works together to provide the science learning experience. It can be used for physics, chemistry, biology, and Mathematics.



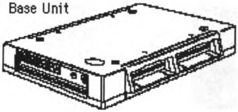
HARDWARE

The hardware for PSL consists of the following components:

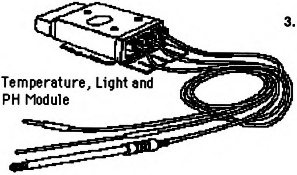


1. Any IBM personal computer with a serial port.

Base Unit



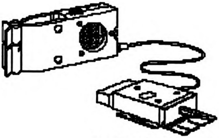
2. The hardware for PSL Base Unit is the hub of PSL hardware, it controls multiple probes at once.



Temperature, Light and PH Module

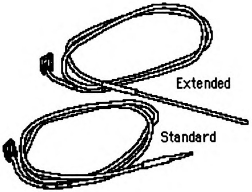
3. Modules can be inserted into any port on the base unit. PSL has two types of modules:

(1) Temperature, Light, and PH module.



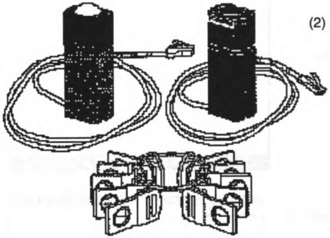
Motion & Mechanics Module

(2) Motion and Mechanics Module.

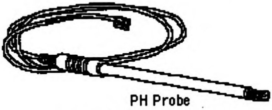


4. Sensor devices can be inserted into the related modules. There are four types of probes:

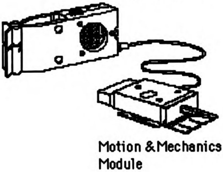
(1) Temperature probe can be used to collect data about temperature.



(2) Light Probe can be used to collect data about the intensity of light .



(3) pH probe can be used to collect data about the pH scale of a liquid.



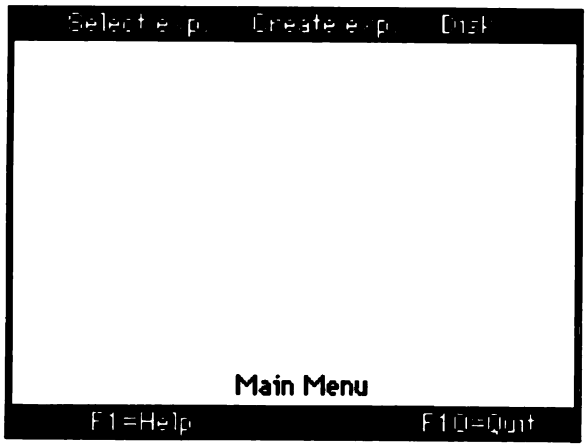
(4) The Distance Probe uses ultra-high-frequency sound to detect the distance.

SOFTWARE

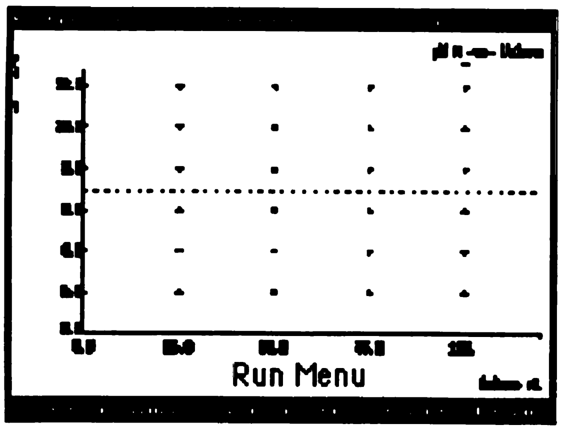
EXPLORER

The software supplied with PSL consists of the PSL EXPLORER. It provides menus for the user to control PSL.

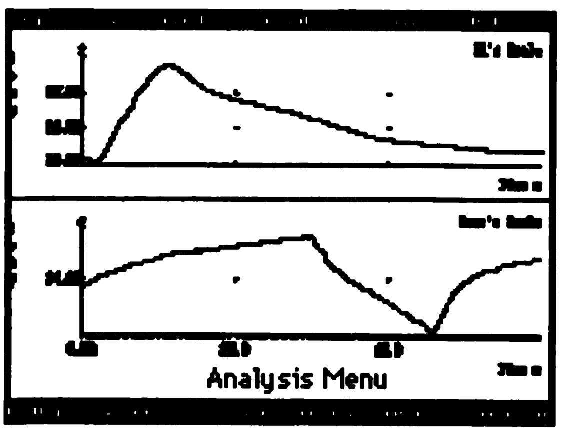
PSL EXPLORER is comprised of three sequential menus:



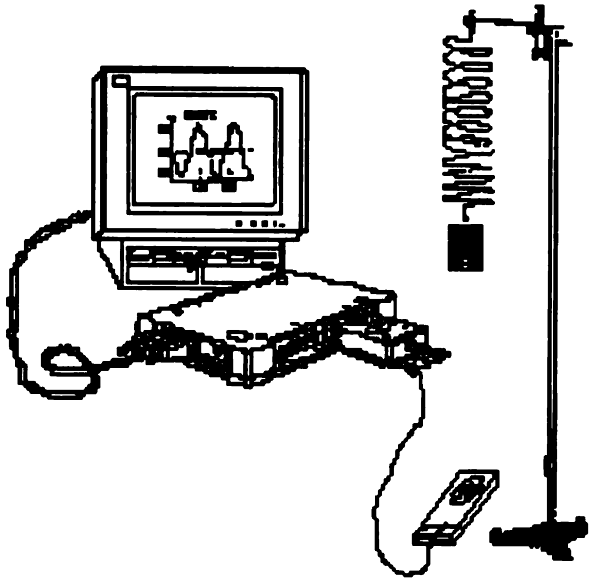
1. The Main menu is displayed when PSL EXPLORER is started. It allows users to select the existing experiment setups or create their experiment setups.



2. This Run menu is displayed after the user accepts an experiment setup. It allows user to perform his or her experiment.



3. This Analysis menu is displayed when the collecting of experiment data is completed. The results of the experiment appear as a graph which this menu enables the user to analysis the data.

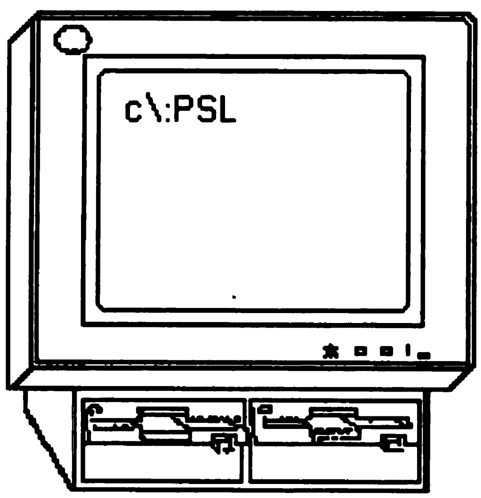


AN EXAMPLE OF USING PSL

--- Mass and Spring experiment

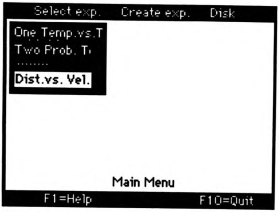
This demonstration which shows how to perform a Mass and Spring experiment step-by-step:

Step-1: Set up the equipment like this.

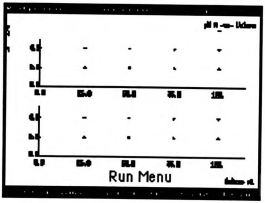


Step-2: Start the software by typing PSL and press Enter key. The Main Menu will be displayed.

Step-3: From the Main Menu, highlight select experiment and press Enter key. A small window appears.

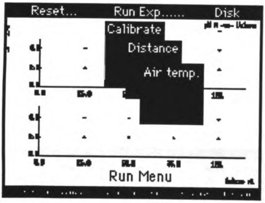


Step-4: Press the down arrow key to move the highlight to Distance and Velocity and press the Enter key in order to select the setup of Distance and Velocity.

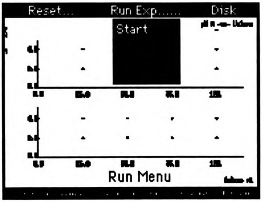


Notice that the screen has been changed from Main Menu to the Run Menu.

Step-5: As the Run Menu is displayed, the experiment is ready to run. Highlight Run experiment and press Enter key.

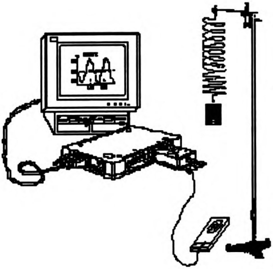


When the first small window is displayed, highlight Calibrate... and press the Enter key. When the second small window is displayed, highlight Distant.... and press the Enter key. When the third small window is displayed, use Arrow and the Enter key to change the Air temperature and Data rate.



Step-6: Press ESC key twice to hide the second and the third small windows.

Step-7: From the first small window, move the highlight to Start. Now it is ready to collect data.

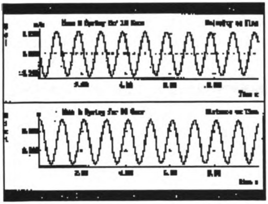


Step-8: Start the Mass and Spring Oscillation.

Step 9. Press the Enter key to start collecting data.

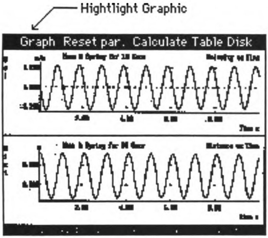
As soon as the collecting data is completed, the screen will be changed from the Run menu to the Analysis Menu.

This signifies that the program is ready to analyze the data you have been collected.

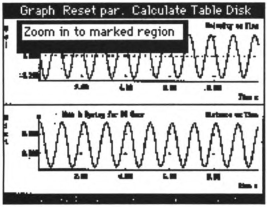


Step-10: Press the F4 key to scale the upper graphic.

Step-11: Press the F2 key to switch the frame to the lower graphic and press the F4 key to scale it.

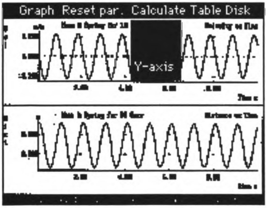


Step-12: Highlight the Graph on the top menu bar and press the Enter key. Move the arrow by pressing the arrow key to the place you wish to see the details.

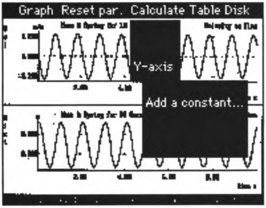


Step-13: Press the M key and arrow key to mark the area you wish to see details. Then press the Z key. A small window will be displayed.

Step-14: Highlight Zoom-in to marked region and press the Enter key.



Step-15: To perform the calculation analysis, press the ESC key. Move the highlight to calculate on the top menu bar then press Enter key. A small window will be displayed.



Step-16: Move the highlight to Y-axis... and press the Enter key. As the second small window appears, select the calculation you want to perform the calculation.

SUMMARY

First: Using **Main Menu** to select or create your experiment set-up.

Second: Using **Run Menu** to calibrate and start collecting data.

Third: Using the **Analysis Menu** to analyze data.

For further information, read Reference Guide to find the information you need.

GOOD LUCK !

APPENDIX B

Survey Questionnaire

Questionnaire One: Items about computer experiences

May I personally assure you that all your responses will be dealt with complete confidence and any writing on this subject by me will contain no references to individuals or schools.

(1) Have you ever used a computer ?

at school

at university

in employment

at home (including games)

other

(2) Can you

load a program

use a program that has been loaded

write a program

connect up a keyboard / monitor / printer

(3) How confident are you about using

hardware

software (computer game, word processing, data base, spreadsheets, statistical analysis software, math science and engineering software)

(4) How confident are you feel about using a computer ?

personally

as a Teacher

(5) How many hours per week do you spend using a computer ?

less than 2 _____ 6-10 _____ over 15 _____

2-5 _____ 11-15 _____

(6) Have you ever taken computer course in school for credit ?

Yes _____ No _____

(7) If so, how many hours credit have you received ?

1-3 _____ 7-10 _____

4-6 _____ over 10 _____

(8) Have you ever had in-service training designed to improve Your computer instruction ?

Yes _____ No _____

(9) How would you rate your level of computer expertise ?

high	above average	average	below average	low

Thank you very much for your help.

Questionnaire Two: Items about subject-matter knowledge

May I personally assure you that all your responses will be dealt with complete confidence and any writing on this subject by me will contain no references to individuals or schools.

(1) Have you ever taken the following science courses in Middle School/High School for credit ?

Science _____ Algebra II _____ Analysis _____

Physics _____ Chemistry _____ Biology _____

(2) Have you ever taken the following science courses in college for credit ?

Physics _____ Chemistry _____ Biology _____

(3) What science courses have you taught in school ? (For teacher only)

Thank you very much for your help.

Questionnaire Three: Items about attitudes measured on a 5-point scale of agreement or disagreement (For teacher only)

May I personally assure you that all your responses will be dealt with complete confidence and any writing on this subject by me will contain no references to individuals or schools.

(1) I would like to learn more about computers as teaching aids.

(2) I don't mind learning about computers.

(3) I could (can) well do without the aid of a computer in my class.

(4) Working with computers in class distorts the social climate.

(5) Computers harm relations between students and teachers.

(6) Computers are valuable tools in improving the quality of a child's education.

(7) Computers can only be useful in a few subjects.

(8) Using a computers in a school enhance students' creativity.

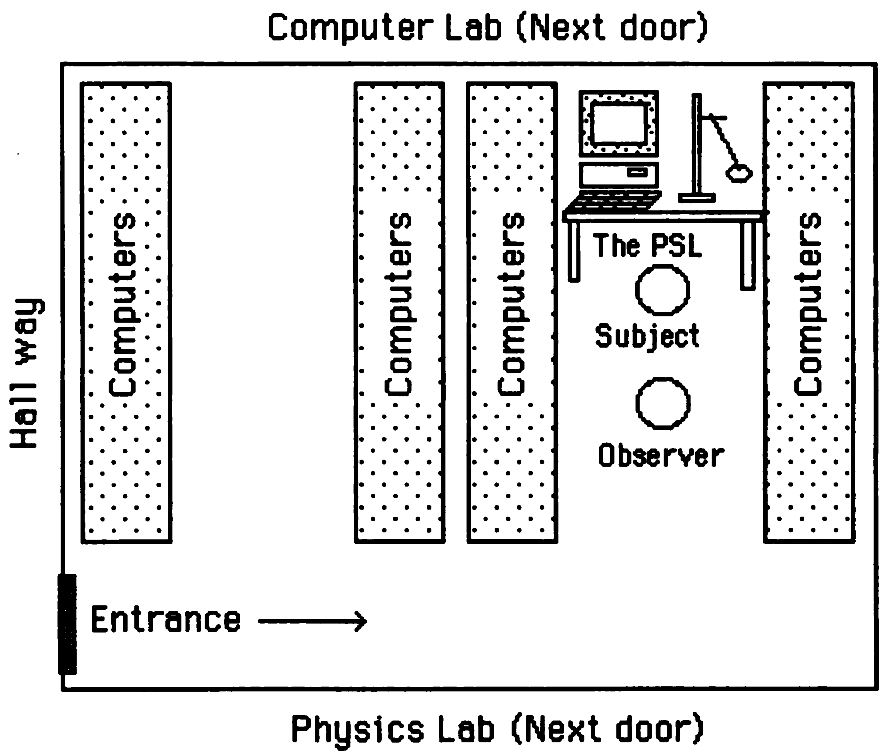
(9) I am interested in using computers in lessons.

Thank you very much for your help.

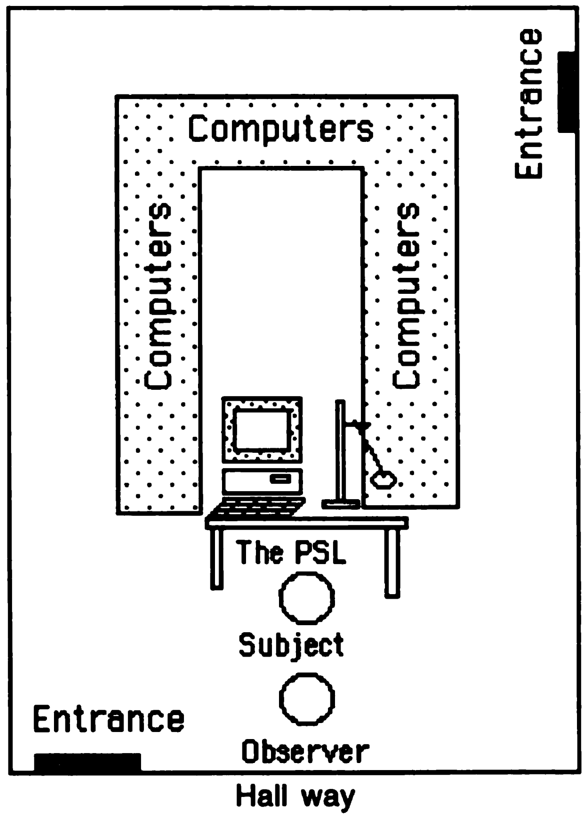
APPENDIX C

RESEARCH SITES

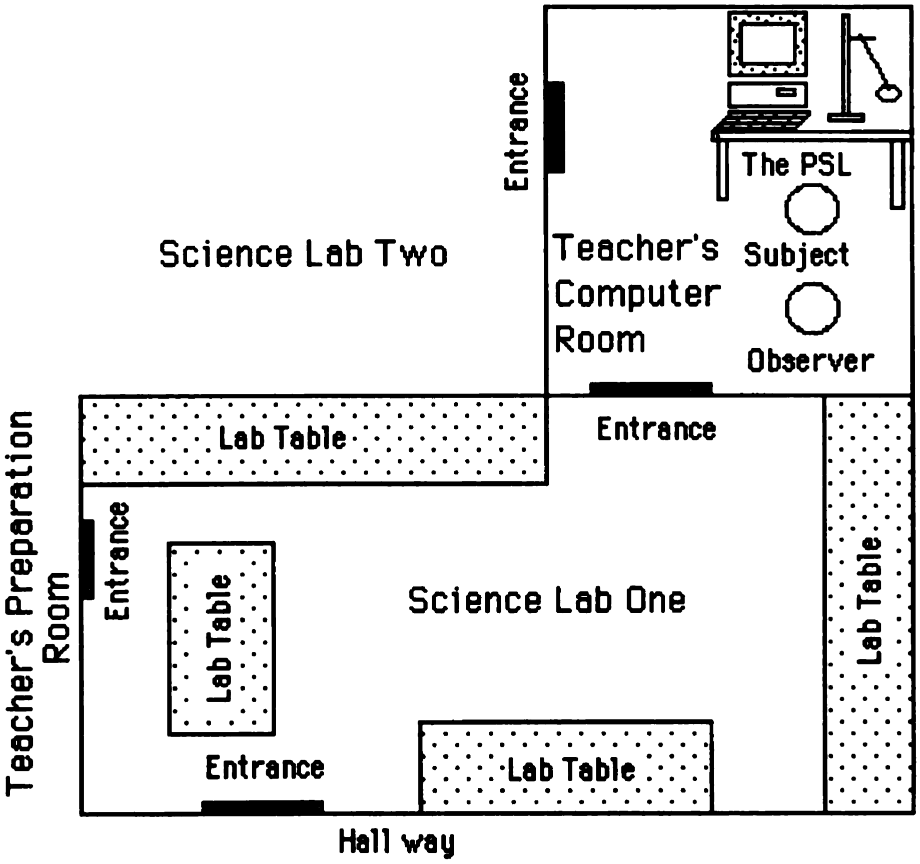
The diagram of the research site in the high school:



The diagram of the research site at Michigan State University:



The diagram of the research site in the middle school:



APPENDIX D

SAMPLE EXPERIMENTS

This appendix contains three sample experiments and one sample exploration. The sample exploration is taken from Personal Science Laboratory Temperature Experiments, Version 1.00.

These activities will teach you how to set up and run your PSL hardware and your PSL Explorer software.

Note: These sample activities can be photocopied and distributed for use only within the school that purchased the PSL Explorer program.

Activity 1: A Simple Temperature Experiment

This activity guides you in choosing and running a one-probe temperature experiment from the list of experimental setups. This is the easiest way to perform an experiment using PSL Explorer and provides a good introduction to the program.

Set Up and Run the Experiment

1. Set up the PSL equipment by doing the following:
   a. Insert the blue Temperature, Light, and pH(TLp) Module into any of the four ports on the PSL Base Unit.
   b. Insert the Standard Temperature Probe into channel 1 of the TLp Module. (The Standard Temperature Probe is the one with the small metal chip on the end; the Extended Temperature Probe is the one with the long metal rod.)

2. Start the PSL Explorer program.
   Refer to "Starting Software" on page 1-2 for instructions on starting the software.

3. After startup, the Main Menu is displayed on your computer's screen.

Figure D-1. Main Menu

Choose **Select experiment** from the Main Menu by doing the following:

a. Use the Left and Right Arrow keys to highlight the Select experiment option at the top of the Main Menu.
b. Press **Enter**. The window that is displayed contains a list of the experimental setups included with PSL Explorer:

Heat of Neutralization
Two Probe Light Pendulum
One Temperature vs. Time
Angle of Polarization
Harmonic Motion
Standard Titration
More

4. Use the Down Arrow key to highlight One Temperature vs. Time and press **Enter**. The screen that is displayed includes almost all the information you need to run your experiment.

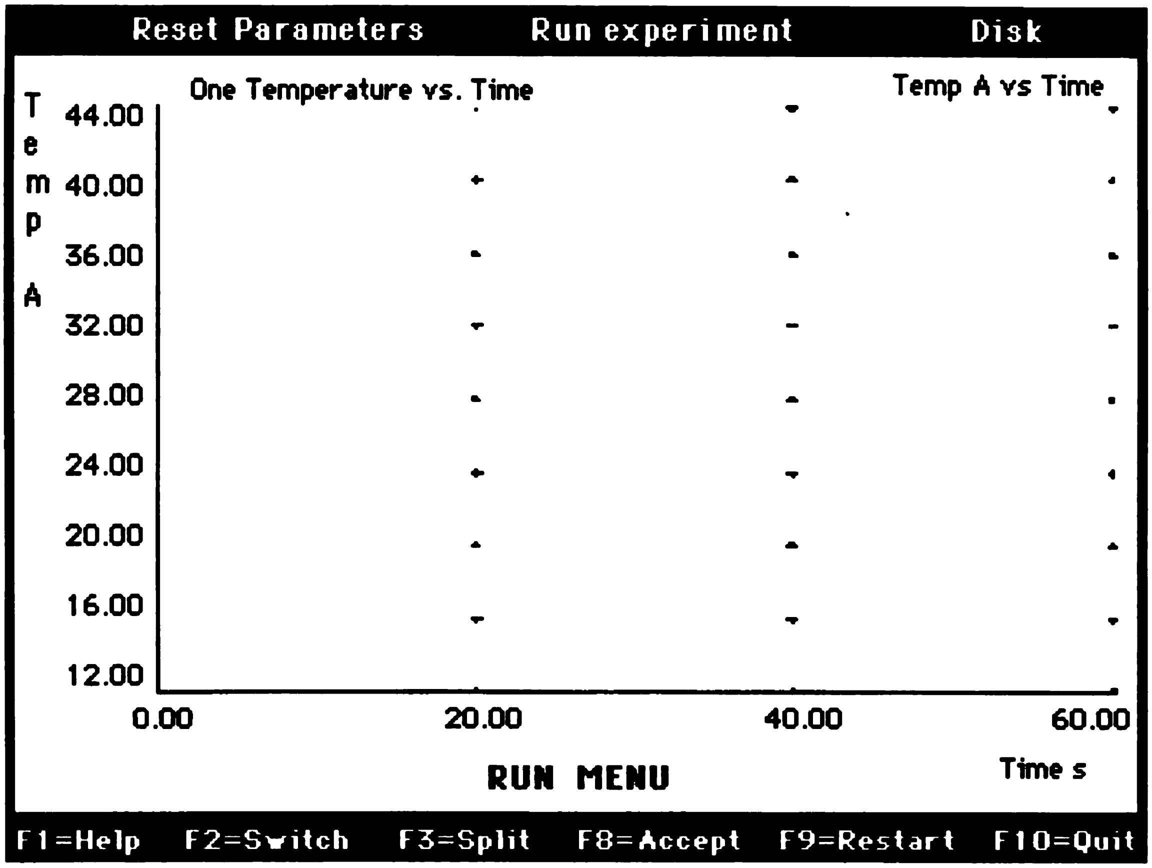


Figure D-2. One Temperature vs. Time Setup Screen

5. Highlight **Run experiment** and press **Enter**. The following window will be displayed Select action

   Start
   Calibrate...
   Preview...
   Set Com...
   View...

6. The next step is to calibrate the temperature probe. Each PSL temperature probe has a label on which you will find a three-digit calibration number. This number adjusts the PSL Explorer program for the slight variations that are normal between probes.

   a. Use Down Arrow key to highlight **Calibrate...** and press **Enter**.
   b. Highlight **Temperature** and press **Enter**.
   c. Highlight **Probe A calibration: 500** and press **Enter**.
   d. Enter the three-digit number found on the cable of your temperature probe. (If there are only two digits add a zero to the end.)
   e. Press **Enter**.
   f. Press **Esc**.
   g. Press **Esc** again to return to the Select action window.
   h. Use the Up Arrow key to highlight **Start** and press **Enter**.

Look at the graph on the screen. The line being drawn across the screen indicates that your computer is measuring the temperature of the room.

7. Let the experiment run for about 15 seconds to establish a graph of room temperature, then touch the probe, wave it in the air, or blow on it and observe the results on the screen.
   - Does the temperature increase or decrease when blow on the probe ?
   - Is this different from you feel when you blow on your skin ? Why ?

8. When the experiment is finished, press F9 to restart the program. The following window will be displayed:

Discard experiment data?
No
Yes

Highlight Yes and press Enter to discard the experiment.

Activity 2: Creating an Experiment

In this activity, you will choose the type of experiment you want to conduct, set up the parameters, collect the data, save the results, and perform some simple analyses of the data.

Set Up the Experiment

1. Set up the PSL equipment by doing the following:
   a. Insert the blue TLp Module into any of the four ports on the base unit.
   b. Insert the Standard Temperature Probe into channel 1 of the TLp Module.

2. Start the PSL Explorer program.
   Refer to "Starting the Software" on page 1-2 for instructions on starting the software.

3. Select the **Create experiment** option from the Main Menu by doing the following:
   a. Use the Left and Right Arrow keys to highlight the **Create experiment** option.
   b. Press **Enter**. The following menu is displayed:

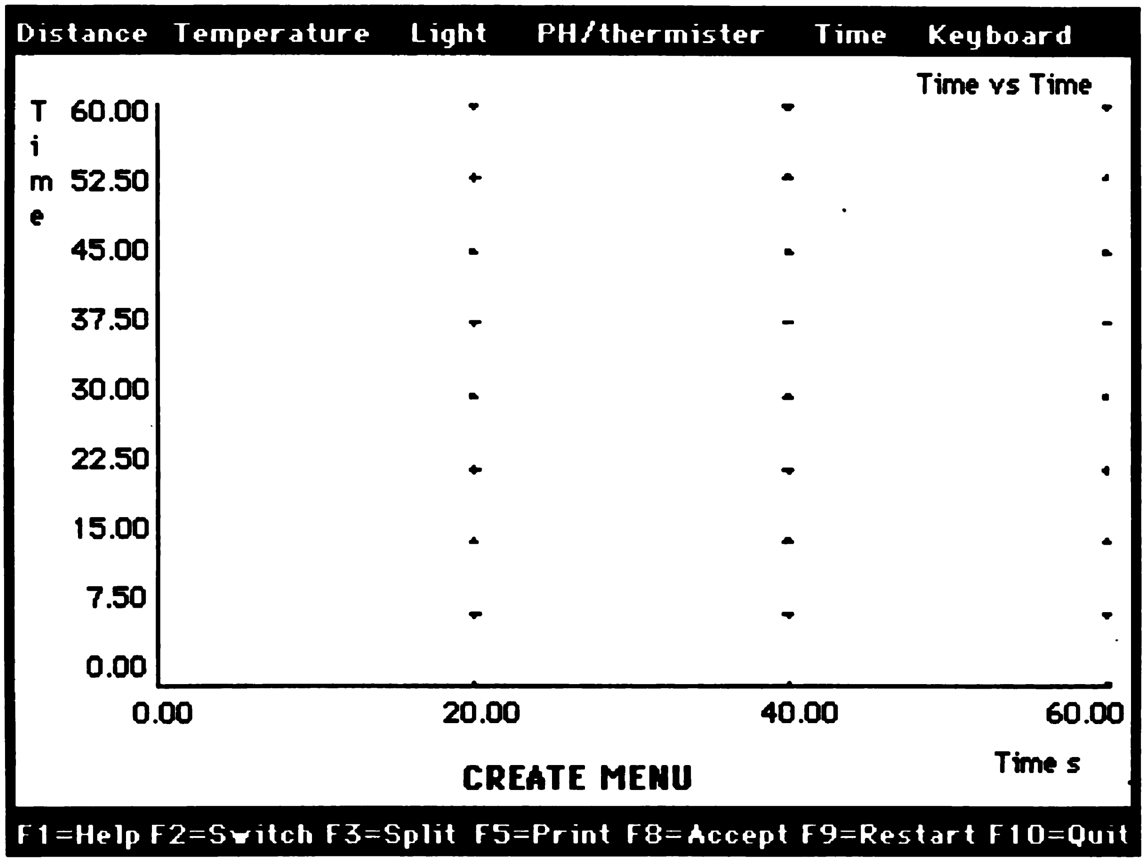


Figure D-3. Create Menu

4. Highlight **Temperature** and press **Enter**.

5. Highlight **Temp A** and press **Enter**.

6. Highlight **Y-axis** and press **Enter**.

7. Press **F8**, highlight **Yes**, and press **Enter** to accept the setup. The Tun Menu will be displayed.

8. Highlight **Reset parameters** and press **Enter**. The following window will be displayed:

Select parameter
Axis variables...
Duration...
Labels...
Numeric format...
Ranges of axes...
Type of plot...

Do the following to define the parameters for the experiment:

a. Highlight **Duration** and press **Enter**.
b. Type 70 for the experiment's duration and press **Enter**. The Select parameter window will disappear and **Reset parameters** will be highlighted.
c. Press **Enter**.
d. Highlight **Ranges of axes** and press **Enter**.
e. Highlight **Y-min (Temp Ain C)** field will be highlighted.
h. Press **Enter**.
i. Type 100 for the maximum (Y-max) value and press **Enter**.
j. Press **Esc** to return to the Run Menu.

9. Before you begin collecting data, it is very important to save the experimental setup you just created so that you can use it again later. You can save the setup by doing the following:

a. Highlight **Disk** and press **Enter**.
b. Highlight **Setup** and press **Enter**.
c. Insert a formatted diskette into drive A. Do not use your PSL Explorer diskette to save your experiments.
d. Press the **Insert** key.
e. Type a name for the setup; the name you type can be as many as eight (8) characters in length and should be a name that you will recognize later.
f. Press **Enter**.
Note: If the message Disk [d] is write-protected is displayed, you must removed the diskette from the drive, locate the lab at the bottom of the backside of the diskette, and slide the tab up. Your diskette is no longer write-protected and you should be able to save your experiment setup. Otherwise, use another formatted diskette that is not write-protected.
g. Type a description of the setup; the description can be as many as 25 characters in length and should be a description that will easily identify the setup.
h. Press **Enter**.

Run the Experiment

1. Fill a 100-mL beaker one-third full with cold water, then fill a second 100-mL beaker one-third full with hot water.
Note: The results you obtain from this experiment will vary depending upon the amount of water you use in the beakers.

2. Place both beakers close to the PSL equipment.

3. Highlight **Run experiment** and press **Enter**. Now, you will calibrate the temperature probe by doing the following:

a. Highlight **Calibrate** and press **Enter**.
b. Highlight **Temperature** and press **Enter**.
c. Highlight **Probe A calibration: 500** and press **Enter**.
d. Enter the three-digit number found on the cable of your temperature probe. (If there are only two digits, add a zero to the end.)
e. Press **Enter**.
f. Press **Esc** twice to return to the Select action window.

4. Hold the temperature probe by the plastic wire. Do not touch the metal probe itself.

5. Highlight **Start** and press **Enter**. Look at the graph on the screen. Your computer is now measuring the temperature of the room.

6. After 10 seconds, place the temperature probe into the beaker of cold water. Watch the screen and notice the program's response to your action.

7. Leave the probe in the cold water for 10 seconds then remove it from the beaker of cold water. Use a tissue to dry the probe, then hold it steady without moving it.

8. After 10 seconds, place the probe into the beaker of hot water. Watch the screen to see the program's response.

9. Leave the probe in the hot water for 10 seconds, then pour the cold water into the beaker of hot water.

10. After 10 seconds, press **Esc** to end the experiment. The Analysis Menu will be displayed when the experiment is completed. This menu allows you to manipulate the data you have collected.

Save and Analyze the Data

Some of the options on the Analysis Menu allow you to change the data you just collected. Always save your collected data before using the Analysis Menu. Save the experimental data you just collected by doing the following:

1. Select **Disk** and press **Enter**.

2. Select **Data** and press **Enter**.

3. Press the **Insert** key.

4. Type a name for the data; the name you type can be as many as eight(8) characters in length and should be a name that you will recognize later.

5. Press **Enter**.

6. Type a description for the data; the description can be as many as 25 characters in length and should be a description that will easily identify the data.

7. Press **Enter**.

8. Press **Esc** twice to remove the windows.

To analyze the data collected by the experiment, do the following:

1. Highlight **Graph** on the Analysis Menu and press **Enter**. Notice that an arrow appears on the graph; you can move this pointer with Left and Right Arrow keys.

2. Use the Right Arrow key to move the pointer to the place on the graph where you put the probe into the cold water.

3. When the pointer is at the beginning of the cold water measurement, type M to begin marking a portion of the graph.

4. Use the Right Arrow key to move the pointer to the place on the graph where you took the probe out of the cold water. Notice that the graph is highlighted as you move the pointer.

5. When the pointer is at the right place, type F to display a window that will enable you to draw the best-fitting straight line for the marked area of the graph. The equation of the line will be displayed in the upper-left corner of the graph. The slope of the line measures the average rate of cooling for the marked area.

6. To enlarge a particular area of the graph for closer examination, type M again to begin marking an area.

7. Move the pointer to the end of the area you want to examine, then type Z to enlarge the marked area of the graph.

Quit and Rerun to the Main Menu

1. Press **Esc** to leave the **Graph** option.

2. Press F9 to return to the Main Menu. The following window is displayed:

Discard experiment setup ?
No
Yes

3. Highlight **Yes** and press **Enter**. The Main Menu is displayed.

Activity 3: Selecting and Running a Two-Probe Experiment

In this activity, you will select a pre-defined experiment and then run it. The experiment you will run uses two temperature probes to collect data. When you run the experiment, the data from the probes will be displayed on two graphs; one for each of the probes.

Set Up the Experiment

1. Plug the Extended Temperature Probe into Channel 2 of the TLp Module.

2. On the Main Menu, highlight **Select experiment** and press **Enter**.

3. Highlight **Two Temperatures vs. Time** and press **Enter**.

4. Fill a 100-mL beaker one-third full with cold water, then fill a second 100-mL beaker one-third full with hot water.

Note: The results you obtain from this experiment will vary depending on the amount of water in the beakers.

5. Place both beakers close to the PSL equipment.

6. Place probe A in the beaker of cold water, then place probe B in the beaker of hot water.

Run the Experiment

1. Highlight **Run experiment** and press **Enter.** The following window will be displayed:

   Start
   Calibrate...
   Preview...
   Set COM...
   View...

You have already calibrated the first temperature probe. Now, you will calibrate the second temperature probe by doing the following:

   a. Highlight **Calibrate** and press **Enter.**
   b. Highlight **Temperature** and press **Enter**.
   c. Highlight **Probe B calibration: 500** and press **Enter**.
   d. Enter the three-digit number found on the cable of the temperature probe. (If there are only two digits, add a zero to the end.)
   e. Press **Enter**.
   f. Press **Esc** twice to return to the Select action window.

2. Highlight **View** to confirm that the probes are in the correct locations. Temp A should be in Port 1, Channel 1; Temp B should be in Port 1, Channel 2.

3. Press **Esc**.

4. Highlight **Start** and press **Enter**. Notice that two graphs are being plotted simultaneously on the screen. Your computer is now measuring the temperature of both the hot water and the cold water.

5. When the experiment is complete (or when you press **Esc**), the Analysis Menu will be displayed. You will notice that the lower graph is framed by a box.

6. Press **F2**. The box framing the lower graph will now move to the upper graph. The graph with the box around it is the active graph. When you perform the operations that are available on the Analysis Menu, they will affect only the active graph.

7. Highlight **Reset Parameters** and press **Enter**. The following window will be displayed:

   Select parameter
   Axis variables...
   Duration...
   Labels...

Numeric format...
Ranges of axes...
Type of plot...

8. Highlight **Labels** and press **Enter**.

9. Highlight **Y-axis name** and press **Enter**.

10. Type probe A and press **Enter**.

11. Highlight **Y-axis units** and press **Enter**.

12. Type deg C and press **Enter**.

13. Press **Esc** to remove the window. Notice that the changes you made affected the y-axis of the top graph only; the lower graph is the same as it was.

14. Press **F2** to switch the box to the lower graph.

15. The highlight bar will be on **Reset Parameters**. Press **Enter**. The Select parameters window will be displayed again.

16. Highlight **Range of axes** and press **Enter**.

17. Highlight **Lower: y-min (Temp B in C)** and press **Enter**.

18. Type 0 and press **Enter**.

19. Highlight **Lower: y-max (Temp B in C)** and press **Enter**.

20. Type 100 and press **Enter**.

21. Press **Esc** to remove the windows. Notice that the changes you made affected the y-axis of the lower graph only.

Save and Analyze the Data

Save the experimental data you just collected by doing the following:

1. Select **Disk** and press **Enter**.

2. Select **Data** and press **Enter**.

3. Press the **Insert** key.

4. Type a name for the data; the name you type can be as many as eight (8) characters in length and should be a name that you will recognize later.

5. Press **Enter**.

6. Type a description for the data; the description can be as many as 25 characters in length and should be a description that will easily identify the data.

7. Press **Enter**.

8. Press **Esc** twice to remove the windows.

APPENDIX E

INTERVIEW QUESTIONS

Level one

Activity 1:

- After activity 1, do you get the general idea about how to use an already existing experiment set-up to perform an experiment? How?
- Answer the two questions in Step 7?

    1) Does the temperature increase or decrease when you blow on the probe?

    2) Is this different from what you feel when you blow on your skin? Why?

Activity 2:

- What is the difference between Activity 1 and Activity 2?
- What big change did you see about the menu after you completed the Step 7 in Set Up the Experiment?
- What big change did you see about the menu after you completed the Step 10 in Run the Experiment?
- After activity 2, do you get the general idea about how to create your own experiment set-up to perform an experiment? How?
- What did you find from the data in this experiment?

Activity 3:

- In Step 2 in Run the Experiment, why is it necessary to highlight **View** to see the locations of each probes? Is this step necessary in Activity 1 and Activity 2? Why or why not?

- In Step 4 in Run the Experiment; If a person pulls out both Temperature Probes (one in the hot water and the other in the cold water) at the same time after 10 seconds, what happens on the computer screen? How do you explain this result?
- How do you think about PSL?

Level two

- What factors affect the period of the simple pendulum?
- If the clock goes faster in the Winter, how will you adjust it?
- If the clock goes slower in the Summer, how will you adjust it?
- What do the new computer graphs mean when you choose a calculation function in the PSL?

Level three

- What is the theoretical foundation of this approximation?
- Could you state the strategy that you used in finding the approximation equation this way?
- Do you feel confident that the approximation equation you obtained adequately represents the real-time data you had collected? Why?
- Do you feel confident when you use the calculations in the PSL program?

APPENDIX F

ADDITIONAL INFORMATION ABOUT THE MBL

The Physics Teacher is a good source of updated information about the PSL. Presently, several companies have advertised new versions of MBL. They are:

1) Kis interface--the former PSL
2) PASCO'S Science Workshop
3) Calculator-Based Laboratory--this version uses a graphic calculator called TI-85 (around $99 in the market)

Some schools may lack the funds for new computers on which to use the PSL package. An alternative can be using old computers. This author tried the PSL package on a very old IBM compatible computer (Zenith) now available at Michigan State University's salvage for $35 (included monitor and keyboard). This computer had only 640K of RAM, and no hard disk drive, only two 5 and 3/4 inch floppy drives. When the PSL software called EXPLORER were separated onto two 5 and 3/4 inches floppy drives. It ran perfectly.

REFERENCES

LIST OF REFERENCES

Arons, A., Achieving Wider Scientific Literacy, Dadalus 112, 91 ,1983

Bacon, R. A., The use of computers in the teaching of physics, Computers Educ. Vol.19, No. 12, 1992 pp. 57-66.

Bogdan, R. C., & Biklen, S. K. (1982). Qualitative research for education: an introduction to theory and methods. Boston: Allyn and Bacon.

Bork, A. (1990), Computers in Learning Physics: What Should We Be Doing ?, the conference on computers in physics instruction, 1990

Bowers, C. A., The cultural dimensions of educational computing understanding the non-neutrality of technology, Teachers College Press Columbia University. New York (1988). pp. 85-115.

Bruner, J. S. (1960) The Process of Education. New York: Vintage Books.

Carramazza, A., McCloskey, M., & Green, B. (1981). Naive beliefs in "sophisticated " subjects: misconceptions about trajectories of objects . Cognition, 9, 117-123.

Chabay, Ruth W., Computer Tutors: Implications of Basic Research on Learning and Teaching, the conference on computers in physics instruction, 1990 p296.

Clement, J. (1983). A conceptual model discussed by Galileo and used intuitively by physics students . In D. Gentner & A. L. Stevens (Eds.), Mental Models. Hillsdale, NJ: Earlbaum.

Collings, P.J, & Greenslade, T.B., Using the computer as a laboratory Instrument, The Physics Teacher, Feb. 1989.

Confrey, J. (1990). A review of research on student conceptions in mathematics, science, and programming. In C. Cazden (Ed.) Review of Research in Education, Vol.16, (pp.-56)

Croxton, Gregory (1993). A Descriptive Study of The Collegiate Experiences of Three Freshman Student-Athletes Who Where Ruled Academically Ineligible for Competition By The National Collegiate Athletic Association MSU, College of Education dissertation

Csete, Josephine Marie. (1994). A Qualitative Study of Needs Assessment: The Culf Between Theory and Practice MSU, College of Education dissertation

DeVries, Paul L. (1993) A first course in computational physics, John Wiley & Sons, INC.

Disessa, A. (1988)., Knowledge in pieces. In G. Forman & P. Pufall (Eds.), Constructivism in the computer age, Hillsdale, NJ: Lawrence Erlbaum Associates, (pp. 49-70).

Erickson, Frederic. Qualitative methods in research on teaching, Handbook of Research on Teaching (3rd ed.). M.C. Witteock, ed. New York: Macmillan Publishing Company. pp. 119-161.

Friedler, Nachmias and Songer. (1989) Teaching scientific reasoning skills: A case study of a microcomputer-based curriculum, School Science and Mathematics, Volume 89 (1) January 1989.

Goetz, J., & Lecompte , M. (1984). Ethnography and qualitative design in educational research. San Diego: Academic.

Guglielmino, Rick, Using spreadsheets in an introductory physics lab, The Physics Teacher, March 1989.

Good, Thomas L. & Brophy, Jere E. (1990). Educational Psychology--A Realistic Approach, Fourth Edition, Longman, New York & London.

Greenslade, Thomas B. (1994). The Coffee and Cream Problem. The Physics Teacher, Vol. 32, March 1994.

Halhoun, L.A., & Hestense, D. (1985 a). The initial knowledge state of college physics students . American Journal of Physics , 53, 1043-1055.

Halhoun, L.A., & Hestense, D. (1985 b). Common sense concept about motion. American Journal of Physics, 53, 1056-1065.

Johnson, David; Johnson, Roger; Johnson, Edythe Holubec, Roy, Patrica (1984). Circles of learning.

Johnson, Karen L., Problem Solving, Pedagogy, and CDC physics, The Conference on Computers in Physics Instruction: Proceedings, p73.

Keller, John (1983). Motivational Design of Instruction, Instructional-Design Theories and Models: An Overview of their Current Status, edited by Charles M. Reigeluth, Lawrence Erlbaum Associates, Publisher.

Keller, John M., Strategies for Stimulating the Motivation To Learn, Performance & Instruction/October 1987.

Laws, Priscilla W., Workshop Physics: Replacing Lectures with Real Experience, The Conference on Computers in Physics Instruction: Proceedings, p24.

Malenka, Margaret Marie (1994). Developing Conceptions of Teaching and Learning: Case Studies of Preservice Teacher's Literacy Experiences in School and Non-School Field Placements MSU, College of Education dissertation

McDermott, L.C. (1984). Research on conceptual understanding on mechanics. Physics Today, 37, 24-32.

McDermott, Lillian. C. (1990). Computers and Research in Physics Education, The Conference on Computers in Physics Instruction: Proceedings, p278.

Ranaweera, Minidasa P., An application of spreadsheets on a computer aided design course, Computers & Education Vol. 14, 1990.

Redish, Edward F.(1990). The Impact of the Computer on the Physics Curriculum, The Conference on Computers in Physics Instruction: Proceedings, pp. 15-17.

Reigeluth, Charles M. (1983), Instructional-Design Theories and Models: An Overview of Their Current Status P338.

Resnick, L.B. (1983). Mathematics and science learning: a new conception. Science, 220, 477-478.

Robertson, Ian; Calder, Judith; Fung, Pat; Jones, Ann and O'Shea, Tim (1995), Computer Educ. Vol. 24, No. 2 pp. 73-81

Roessler, Michael J. (1987) Fourth grade and computers: a case study , Doctorate Dissertation, Department of Education, Michigan State University.

Roschelle, Jeremy, Learning by collaborating: convergent conceptual change, The Journal of the Learning Sciences, Vol., No., 1992.

Roth, Wolff-Michael (1992) Bridging the gap between school and real life: Toward and integration of science, mathematics, and technology in the context of authentic practice, School Science and Mathematics, Volume 92(6), October 1992

Seiger, Bruce (1990). IBM's PSL Promotes Hands-On Learning, Electronic Learning, March 1990

Spradley, J. P.(1982) Participant observation. New York: Holt, Rinehart and Winston.

Signell, Peter S. (1990). Computers and the Broad Spectrum of Educational Goals, The Conference on Computers in Physics Instruction: Proceedings.

Slavin, Robert; Sharan, Shlomo; Kagan, Spencer; Lazarowiz, Rachel Hertz; Webb, Clark and Schmuck, Richard (1985), Learning to cooperate, cooperating to learning, Plenum Press, New York and London

Sneider and Barber. (1990) The New Proware: Science Labs in a Box, Technology & Learning, October 1990

Soloway, Elliot. (1994) Way of Seeing, Communication of the ACM, February 1994/Vol. 37, No. 2

Stipek, Deborah J. (1988) Motivation to learn--from theory to practice, Prentice Hall

Taylor, D.W., O'Shea, T., Sellman, S.R., Clark, P. and O'Malley, C.. Challenging models of elastic collisions with a computer simulation, Computer & Education, Vol. 20, No. 1 pp.-9 1993.

Taylor, Edwin F. (1990). What Works: Settings for Computer Innovators in Physics Education, The Conference on Computers in Physics Instruction: Proceedings.

Tesch, R. (1990). Qualitative research: Analysis types and software tools. New York: The Falmer Press.

Toepker, Terrence P. (1993). Galileo's Damped Oscillator, The Physics Teacher, Vol. 31, Dec. 1990

Thornton, Ronald K (1987). Tool for scientific thinking---microcomputer-based laboratories for physics teaching, Phys. Educ. 22 (1987)

Thornton, Ronald K. & Sokoloff, David R. (1990). Learning motion concepts using real-time microcomputer-based laboratory, Am. J. Phys. 58 (9), September 1990

Trowbridge, David E. (1990). Applying Research Results to the Development of Computer Assisted Instruction, The Conference on Computers in Physics Instruction: Proceedings.

Turkle, S. (1984). The second self: Computer and the human spirit. New York: Simon and Schuster.

Viennot, L. (1979). Spontaneous reasoning in elementary dynamics. European Journal of Science Education, 1, 205-221

Walter, R. Kenneth, Simulating physics problems with computer spreadsheets, The Physics Teacher, March 1989.

Watl, D., Education for citizenship in a computer-based society. Computer Literacy (Edited by Seidel R., Anderson R. and Hunter B.). Academic Press, New York (1982).

Wells, Gordon & Chang-Wells, Gen Ling (1992). Constructing Knowledge Together, Heinemann, Portsmouth, NH

Wilson, Jack M. (1990). Changing the Introductory Physics Sequence to Prepare the Physics Student of the 1990s, The Conference on Computers in Physics Instruction: Proceedings.

Wlodkowski, Raymond J. (1978) Motivation of teaching: A practical guide, A national education association publication

Yu, Yelu (1982). Theory of educational communication and technology, paper presented in a conference on Educational Communicational and Technology at South China Normal University in 1982.