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TOOLS FOR SCIENTIFIC THINKING: MICROCOMPUTER-BASED LABORATORIES FOR THE NAIVE SCIENCE LEARNER

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ABSTRACT

A promising new development in science education is the use of microcomputer-based laboratory tools that allow for student-directed data acquisition, display, and analysis. Microcomputer-based laboratories (MBL) make use of inexpensive microcomputer-connected probes to measure such physical quantities as temperature, position, velocity, acceleration, sound, light, force, and physiological indicators such as heart rate. MBL gives the naive science learner unprecedented power to explore, measure, and learn from the physical world. Carefully developed software makes these laboratory tools easy to use without dictating the steps of an investigation. Consequently, these tools can be used with most curricula and even, with little modification, by students from elementary school to college. Data are taken and immediately displayed in digital and graphical form. Data can then be analysed, transformed, printed, and saved onto disks.

The data and experiences discussed in this paper result from two projects. The Microcomputer-Based Laboratory Project at the Technical Education Research Centers (TERC) in Cambridge, MA, is funded by the National Science Foundation and is primarily concerned with the development and dissemination of MBL materials for middle school science. "Tools for Scientific Thinking" is a project of the Center for Science and Mathematics Teaching at Tufts University. A major purpose of this project is the introduction of MBL at the college level. The initial audience is naive science learners, primarily students of the humanities who take science courses. Special attention is being paid to the needs and interests of women in science courses and to those students with science anxiety.

This paper discusses the use of a MBL motion probe in two very different settings-- a sixth grade classroom in a public school and in two college physics courses at Tufts University which are primarily designed for humanists. The hardware and software used in the two settings was essentially the same and even the written materials had many simularities. A motion detector, developed from a sonic transducer used in Polaroid cameras, was used to teach relationships among the position, velocity, and acceleration of objects as a function of time by the use of immediate (real-time) graphical representations shown on a computer screen. In both cases the motion of the students' own bodies was initially used to teach the concepts involved. Results of observations, written work, and exams show substantial student understanding of motion and graphing. Preliminary observations indicate that the linking of concrete measurement of an actual physical system with the simultaneous production of the symbolic representation may be an effective way for students to learn to correctly interpret and produce graphs.

From the experiences described in this paper and from other similar experiences it would seem that MBL is effective for teaching science to students with a wide range of abilities and ages. MBL gives students an opportunity to investigate their "common sense" understandings of science. When MBL probes are well designed with good user interfaces and used properly as tools to aid scientific thinking, microcomputer-based laboratories can be a powerful adjunct to science instruction.

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Institutional Involvement

The data and experiences discussed in this paper result from two projects. The Micro-computer-Based Laboratory Project at the Technical Education Research Centers (TERC) in Cambridge, MA is funded by the National Science Foundation and is primarily concerned with the production and dissemination of MBL materials (hardware, software, and curriculum units) for middle school science. "Tools for Scientific Thinking" is a project of the Center for Science and Mathematics Teaching at Tufts University. A major purpose of this project is the introduction of MBL at the college level. The initial audience is naive science learners, pri-marily students of the humanities who take science courses. Special attention is being paid to the needs and interests of women in science courses and to those students with science anxiety. The use of MBL for science majors is being co-developed at Tufts but will not be discussed in this paper.

Microcomputer-Based Laboratory Units

The broad range of MBL units being developed at TERC is shown in Figure 1. By concentrating on a single MBL probe, I hope to provide sufficient information to explain MBL without an actual demonstration. To illustrate some of the pedagogical strengths of MBL, I will discuss the use of this MBL probe by science students in two very different settings. A motion detector, developed from a sonic transducer used in Polaroid cameras, is being used to teach relationships among the position, velocity, and acceleration of objects as a function of time by the use of immediate (real-time) graphical representations shown on a computer screen. Although this motion detector was used with two rather different audiences -- 6th grade school children and students of the humanities at Tufts University -- the hardware and software were substantially the same for both groups. The written materials were somewhat different. In both cases the motion of the students' own bodies was initially used to teach the concepts involved.

The motion detectors are typical of other TERC-developed MBL probes in that they give the user a way to measure physical quantities and display them graphically at the moment of measurement. After the measurement, the data can be transformed (by changing the graph scales, for example), printed, or saved onto disks for later analysis. The software associated with the motion detector is also typical of the style developed at TERC in that it is tool-based. That is, it makes it easy for the user to take measurements but does not tell the user what measurements to take. Students do not have to know anything about computers to use MBL since the menu-driven software makes the use self-explanatory. (Quite unlike a storage oscill - iscope which might be used in a similar way as an investigatory tool.) On the other hand, although the software is self-explanatory, it does not automate the student out of the learning process. The student remains in control.

The Motion Detector

The motion probe is essentially a SONAR unit that sends out short pulses of high frequency sound (50 kHZ), then detects and amplifies the echo (much as a bat does). A microcomputer can then measure the time between the transmitted and received pulse and calculate position, velocity and acceleration of the object causing the reflection. The motion detector can accurately detect objects between 0.5 and 5 meters. It detects the closest object in a roughly 30 degree cone. A position and velocity print-out of the screen that resulted from the motion of a weight on a spring (a form of simple harmonic oscillation) is shown in Figure 2. Acceleration can also be plotted. The motion detectors used in the following examples were connected to Apple II computers (the motion software and hardware is also being developed for Commodore 64's.) A well-designed measurement tool is not enough to insure that science learning takes place in most situations. Accompanying curricula (usually print materials) are best designed to guide the student through investigations and to her/his own investigations without setting up "cookbook" exercises.

MBL Motion Unit for Middle School

The motion unit was presented to five different sixth grade classes in a public school located in an affluent suburb of Boston. Over one five-day week for one 50-minute period a day the students worked in groups of three or four using motion detectors. There were five motion detectors in a single science classroom. As the students moved their bodies or rolled toy cars up and down boards propped up on books they were able to watch the graph being drawn simultaneously on the screen (see Figure 3). Students also were asked to reproduce graphs included in the written laboratory materials by moving in an appropriate way. Such choreography required students to be able to interpret graphs and act on their interpretation. Students were able to use the computers and control the graphing after a few minutes of instruction. Masking tape stuck to the floor was marked off in meters to allow the students to measure distances. At the beginning of the second day, the great majority of the class--both girls and boys--were volunteering to answer quantitative questions about the motion implied by distance-time graphs drawn on the board, and their answers were correct. Class discussions and test results showed that students had a sophisticated understanding of motion and of position and velocity graphs. There was also evidence from the observational notes that the students' understanding of motion was solid and not easily changed by counter-suggestion. The following is such an example from the observational notes.

> The girls made a velocity graph of a cart that was speeding up. Their graph correctly showed a positive slope. As they began answering work - sheet questions about the graph, the teacher came over and told them that their graph was wrong. "No, it's not," replied one of the girls, "see how it get's 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.

And indeed they did get it right and showed an impressive understanding of velocity.

These students had not previously been introduced to motion and had only a short introduction to graphing in the fifth grade. The preliminary conclusion drawn from this experience is that the MBL motion unit can be an effective means of teaching middle school students to understand motion and graphing. Further studies are underway to check these conclusions.

MBL Motion Laboratory for Humanities Students

With the cooperation of the two professors involved, I designed a motion lab and introduced it into two courses for non-science majors in the Physics Department at Tufts University; Physics for Humanists (36 students) and Physics of Music and Color (22 students). The lab work was similar in most respects to that done with the sixth graders but less repetitive. In one 50-minute lab period the students were introduced to distance and velocity graphing using the motion of their own bodies. Although some motion involving changing velocities was required, there were no exercises directed to understanding acceleration in this first laboratory.

The college students seemed to enjoy the lab as much as the sixth graders and were fully engaged. In mixed groups of men and women, women took leadership roles as often as men. Groups of three seem to work well pedagogically. Group members were asked at the beginning of the period to rotate among the various jobs: directing (coaching) the moving, moving, and controlling the computer. Students shared these roles without further prompting. A few minutes of explanation were sufficient for students to operate the computers without trouble. No group had any trouble with the software or with completing the laboratory exercises. The level of understanding was high, judged from the answers to questions asked verbally, the discussion of students among themselves, and the filled out laboratory sheets. A few examples of lab exercises are shown in Figure 4. There were a number of examples of students doing their own investigations to answer original questions during the laboratory and some students were reluctant to leave at the end of the period even though their labs were done. It is hard to think of a better student response to a laboratory.

The students were given homework which built upon their laboratory experience and required a solid understanding of distance and velocity graphs as well as the relationship between the two. A few sample problems are shown in Figure 5. The student success in answering this homework exceeded all of my expectations based on many years of teaching science to humanities students. The mean and the modal was 24 out of 25 possible points. The distribution is shown in Figure 6. All students (essentially) answered questions dealing only with distance time graphs entirely correctly. A small number of students interpeted velocity graphs as distance graphs for most velocity questions (this was true for the middle school as well). This error accounted for most of the lower scores. The women seem to have a broader distribution of scores than the men (the highest and the lowest). I have no idea from this sample whether the distribution is significant in any way.

The Physics for Humanists students were given a midterm examination that contained 35 out of 115 points on motion graphing. Questions involving graphs of accelerating objects were included. This information was covered in lectures and some MBL class demonstrations but students had no direct laboratory experience with acceleration. The questions are shown in Figure 7. More than half the class clearly understood all six questions. (Scores better than 33 out of 35 points) As predicted, the error rate on question 2b), which was not covered in any manner in the laboratory or associated homework, was much larger than the other three questions of similar form. (12.5 errors out of 32 responses compared to 2 errors out of 32 for the other questions.) A small number of students continued to confuse distance and velocity graphs which led to some low scores. There is certainly more work to be done. The distri - bution is shown in Figure 8a. Out of 32 students only four did significantly worse on the motion portion of the exam then on the rest of the questions. All have very low overall scores. (The lowest score happens to be that of a student who missed the laboratory although he did the homework.) My past experience would indicate the motion portion to be more difficult than the rest of the exam for students of the sort included in this sample.

The same questions (without reference to a motion detector) were given to a small sample of physics students in a section of a freshman physics-for-majors course right after they finished kinematics. The results are shown in Figure 8b. It would seem from this small sample that many humanities students in this course understand these aspects of motion as well as the students who have received a traditional mathematical treatment of kinematics in a freshman majors course.

Although the statistics of actual measurements are weak and some evidence is based on inexact comparisons with past teaching experiences, the single hands-on MBL laboratory introduced into these courses seems to have had a positive pedagogical effect. The following quote indicates the reaction to the MBL laboratory of the professor who taught Physics for Humanists.

> Their [student] involvement and enthusiasm was striking and nearly unamimous. This circumstance was noteworthy given the composition of the class -- non-science majors with little experience in laboratory settings and some suspicions about computers.
>
> The students participated with both seriousness and playfulness. The explicit instructions were followed with ease. Students seemed to be sincerely engaged in trying to understand the meaning of the activities. Furthermore, the involvement of the students indicated no male-female distinctions.
>
> All in all, the experiment proved to be one of the more successful that I have conducted in my many years of teaching. I intend to repeat this in coming years and would be pleased to see similar MBL experiments included in our other physics courses.

Educational Advantanges of Microcomputer-based Laboratories

The following educational advantages seem to be supported by my experiences and those of others who have used MBL.

1) MBL gives students the opportunity to explore and quantify the physical world (that which we can directly touch, taste, hear, and see and part of that which we can't) using sensors that are not commonly available to students. Using MBL, it is possible to measure phenomena over time scales that are both shorter and longer then can ordinarily be conveniently used.

2) Although the student is still in control of the data taking many of the tedious aspects of measuring, storing, and displaying data are eliminated and the student is able to pay attention to understanding the science behind the data. Students more often have the time and inclination to ask their own "what if" questions.

3) These phenomenological data are stored and can be reviewed and manipulated in such a way to make it easy for the student to use the information as a basis for hypothesis development and model building.

4) Preliminary evidence from middle school and college indicates MBL is an effective means of teaching students to understand and constructively use scientific symbol systems such as graphing. The effectiveness may be the result of the immediate linking of a concrete measurement of an actual physical system with the simultaneous production of the symbolic representation.

5) Preliminary evidence indicates MBL can work well with women (girls) as well as men (boys) and may well be an aid rather than a hindrance to those with science anxiety.

Continuing Work

Most of the completed research has been preliminary. Our initial conclusions will be checked by more formal research concerning the usefulness of MBL in teaching science to students of all ages. MBL probe and middle school materials development is continuing at TERC. The first four units listed in Figure 1 should be commercially available by the 1985-86 school year from HRM in Pleasantville, NY.

The development and testing of college-level laboratory curriculum materials for both majors and non-majors is continuing through the Center for Science and Mathematics Teaching at Tufts. Instructor-performed demonstrations using MBL probes are also being developed and have been found to help student understanding but seem less effective than student-controlled laboratory investigations. A collaboration of individuals interested in developing and using MBL at the college level is being formed. More information may be obtained from the author.

Conclusions

From the experiences described in this paper and from other similar experiences it would seem that MBL is effective for teaching science to students with a wide range of abilities and ages. MBL gives students an opportunity to investigate their "common sense" under - standings of science. When MBL probes are well designed with good user interfaces and used properly as tools to aid scientific thinking, microcomputer-based laboratories can be a powerful adjunct to science instruction.

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Figure 1: Selected MBL Units with Related Disciplines and Hardware Requirements

	Discipline					Hardware		
	[illegible]	Chem	Physics	Earth	Tech	None	Low-level interface	Universal interface
1. Heat and Temperature		•	✓				✓	
2. Sound	•		✓		•			✓
3. Motion			✓				✓	
4. Illusions	✓				•	✓		
5. Musical Sounds	•		✓					✓
6. Reaction Time	✓				•	✓	•	
7. Force	•		✓				✓	
8. Flame		✓	•				✓	
9. Solar			•	✓	•		✓	
10. Microenvironments	c	✓		•			✓	
11. Perception	✓		•				✓	
12. Seismic Waves			•	✓				✓
13. AC Power			✓		•		✓	
14. MBL Hardware					✓		✓	•
15. MBL Software					✓		✓	
16. Radioactivity			✓	•				✓
17. Weather			•	✓			✓	•
18. ECG Heart	✓				•		✓	•

✓ = major emphasis
• secondary emphasis

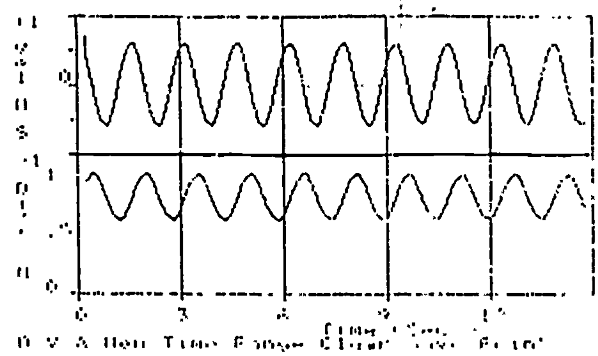

Figure 2: Screen print-out of position and velocity graph produced by the motion detector "watching" a weight on a spring. (A form of simple harmonic oscillator.)

Figure 3: Sixth graders in an MBL motion laboratory. The motion detector is the small box on the stand.

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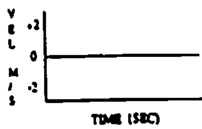
[Selected] Exercises from the Motion Laboratory

[Make] a distance graph walking medium [speed] away from the detector and then [walking] fast toward the detector. [Sketch] the graph.

[Make] a velocity graph walking slowly and steadily away from the detector. Sketch the result here.



Draw below your prediction of the graph if a person:

a) Starts at the 1-meter mark, walks steadily and slowly away, stops for four seconds, and then walks quickly back.

b) Compare predictions. See if you can all agree.

c) Do the experiment and repeat until you find an answer that seems correct.

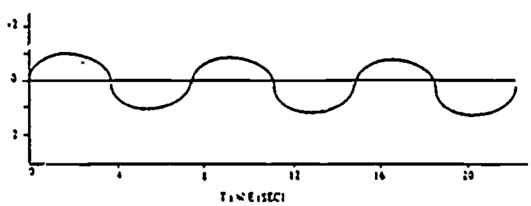
d) Draw your group's final result on the second graph.

Note: Put in the time and distance scale.

PREDICTION

FINAL RESULT

4. Make a graph that looks like the wave pattern shown below. Try to get the times right and the speeds right.



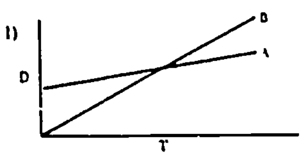
Checked by instructor

Figure 5: Selected Problems from Motion Homework

C. How do you walk to create a straight line that slopes down?

D. What does it mean when a line on your graph goes up steeply and then continues up gradually?

1)

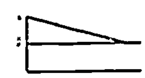


a) Which is faster? (A or B)

b) Which starts ahead?

c) What does the intersection mean?

c) How do you move to create a straight line velocity graph that slopes down?



2. Figure out the distance the object traveled in the graph below. (Show your work).

Distance = ____________ meters.

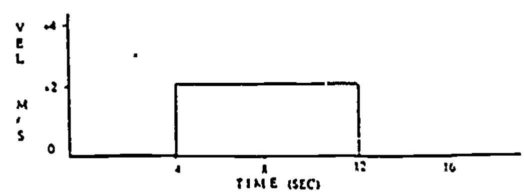


Figure 6: Scores on Motion Homework

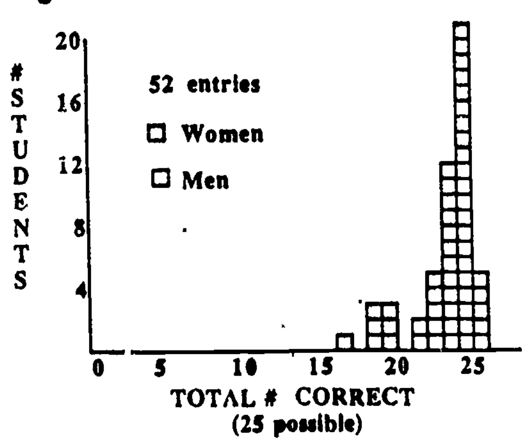


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Figure 7: Motion Questions from Physics for Humanists Midterm

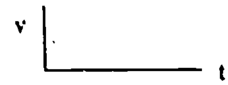
2. Recall the motion laboratory when answering the following
Draw an approximate distance graph for the position of a person walking away from the detector with

a) constant speed

b) constant acceleration

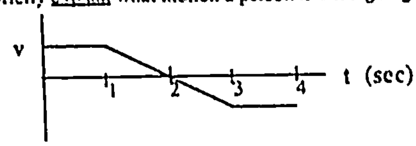
Draw an approximate velocity graph for a person walking away from the detector with

c) constant acceleration



d) zero acceleration

e) Briefly explain what motion a person is undergoing to produce the velocity graph below.



f) If the person started at zero distance, draw the distance graph corresponding to the velocity graph shown in e).

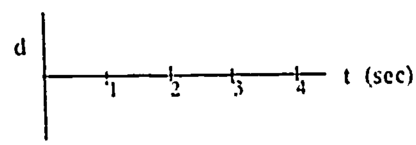


Figure 8a: Motion part of mid-term exam
Scores of Physics for Humanists

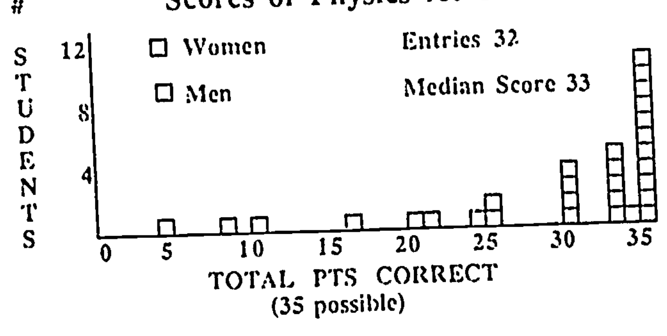
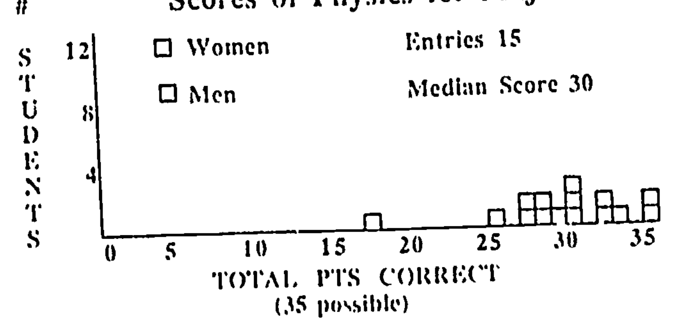


Figure 8b: Motion part of mid-term exam
Scores of Physics for Majors



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