JOURNAL OF RESEARCH IN SCIENCE TEACHING VOL. 27, NO. 8, PP. 803-815 (1990)

THE EFFECT OF SIMULTANEOUS MOTION PRESENTATION AND GRAPH GENERATION IN A KINEMATICS LAB

ROBERT J. BEICHNER

State University of New York at Buffalo, Buffalo, New York 14260

Abstract

Real-time microcomputer-based Lab (MBL) experiments allow students to "see" and, at least in kinematics exercises, "feel" the connection between a physical event and its graphical representation. In Brasell's (1987) examination of the sonic ranger MBL, a delay of graphing by only 20 seconds diminished the impact of the MBL exercises. This article describes a study where kinesthetic feedback was completely removed by only giving students visual replications of a motion situation. Graph production was synchronized with motion reanimation so that students still saw a moving object and its kinematics graph simultaneously. Results indicate that this technique did not have a substantial educational advantage over traditional instruction. Since Brasell and others have demonstrated the superiority of microcomputer-based labs, this may indicate that visual juxtaposition is not the relevant variable producing the educational impact of real-time MBL. Immediate student control of the physical event and its graphical representation might be what makes MBL effective and, in the case of kinematics laboratories, kinesthetic feedback could be the most important component of the MBL learning experience. Further studies are needed in order to clarify this point.

Recent studies note that microcomputer-Based Laboratory (MBL) experiences are useful in helping students understand the relationships between physical events and graphs representing those events (Barclay, 1986; Mokros & Tinker, 1987; Thornton, 1986; Tinker, 1986). Research indicates that it is the real-time nature of MBL that accounts for the improvement in student achievement (Brasell, 1987). In other words, the effectiveness of the technique stems from the fact that the situation being examined by the student is actually occurring while the graphs relating to that event are being produced.

This study began as an attempt to examine the educational impact of just the visual juxtaposition of a motion event with the corresponding kinematics graphs (the "VideoGraph technique"). The original intent was to show that merely seeing a recreation of the event in the form of a computer animation of videotaped images was sufficient to let students learn significantly more than the traditional kinematics lab experiments allow. This hypothesis proved to be incorrect. Although the VideoGraph students had higher scores than did the traditional groups, this difference was not large enough to be statistically meaningful.

Published by John Wiley & Sons, Inc. CCC 0022-4308/90/080803-13$04.00

Graphing Motion

It appears that knowledge of graphs gained in a mathematics class does not transfer to a thorough understanding of their meaning and use in studying physical phenomena. The problems students have in this area have been described in McDermott, Rosenquist, and van Zee (1987) and van Zee and McDermott (1987). These studies demonstrated that students taking introductory high school and college-level physics classes understand the basic concepts of graph construction, but fare poorly when asked to explain the concepts conveyed by the graphs.

Clement, Mokros, and Schultz (1986), Mokros and Tinker (1987), and Bell, Brekke, and Swan (1987) indicate that two graphing errors are very common. The first of these might occur when a student is asked to draw a speed versus time graph of an object rolling down a hill. Many students produce incorrect speed graphs which look like the hill traversed by the object. It is easy to see how the path of the object is mistakenly taken as a cue in drawing the speed graph. This type of error may indicate that students view graphs as something concrete rather than as indicators of abstract trends. Niedderer (1987) notes that making abstract things concrete is part of a student's "Matrix of Understanding"—the corpus of all dispositions that influence the way a person deals with problems. The second error commonly seen is a confusion of the slope of a line with a point on the line. For example, students asked to find the place of maximum change in a graph (i.e., where the slope is steepest) sometimes indicate the point of largest value. In general, people have a hard time distinguishing between a quantity and the change of that quantity (Lockhead, 1980).

Microcomputer-Based Labs and Real-Time Graphing

It has long been known (Adams, 1965) that for most computer-assisted instruction to be effective, ". . . it is essential that the user be . . . in direct and immediate communication with the machine . . ." (p. 2). This appears to be especially true when computers are used for real-time graphing—the situation where data is graphed while it is being collected. Several researchers (Brasell, 1987; Mokros & Tinker, 1987; Thornton, 1986) suggest that this simultaneity of a real physical event and its graphical representation may facilitate a mental linking between the two. "The real-time graphical display of actual physical measurements of dynamic systems directly couples the symbolic representation with the actual physical phenomena" (Thornton, 1988, p. 1). The theory behind their arguments notes that real-time graphing lets the student process the event and its graph simultaneously rather than sequentially. Since working memory has a limited capacity and retention time (Hulse, Egeth & Deese, 1980), the simultaneous presentation of event and graph "makes the most" of the cognitive facilities available. This should make it easier to transfer the event-graph unit (already linked together) into long-term memory as a single entity. Perry and Obenauf (1987) suggest that this temporal alignment is important to reasoning about motion. More generically, Shuell (1986) notes that "Contiguity (the proximity of two events) is well established as one of the fundamental variables affecting traditional types of learning" (p. 426).

While examining real-time graphing on a perceptual level, Brasell (1987) points out that movement in a computer display tends to capture students' attention, thus causing them to attend selectively to the important parts of the graph (i.e., those places where changes in the physical event cause changes in the graph). Mokros and Tinker (1987) note that graphs allow humans to use their powerful visual pattern recognition facilities to see trends and spot subtle differences in shape. Linn, Layman, and Nachmias (1987) commented that since real-time graphs are formed while the experiment is being carried out, students are more likely to see the graphs as dynamic relationships rather than static pictures. This implies that MBL treatments should be especially good at reducing "graph as picture" errors, and in fact, this has proven to be the case (Mokros & Tinker, 1987).

The study described here was an attempt to partly determine which aspects of the MBL's real time nature are critical. If simultaneity of perception is the important variable, then perhaps a simple video recreation of the motion event alongside its graph would be enough to help the students link the real event with the graph. The VideoGraph technique does just that. It does not actually perform real-time graphing. The data would have been captured earlier, either by the student or the instructor (as in this study). But video images of the event are displayed on the computer screen, in an animated movie-like fashion, while the relevant graphs are generated as the movie "plays." If the simultaneous perception of motion and graph is the critical educational experience, then the VideoGraph methodology should be as effective as real-time MBL exercises.

There were other reasons to believe that the VideoGraph software would be a useful teaching tool. The research version of the program was essentially a simulation since students did not see the actual event which produced the images. A study by Reed and Saavedra (1986) indicated that a computer simulation of motion events was capable of improving students' conception of average speed. We hoped to see the same sort of impact on our students.

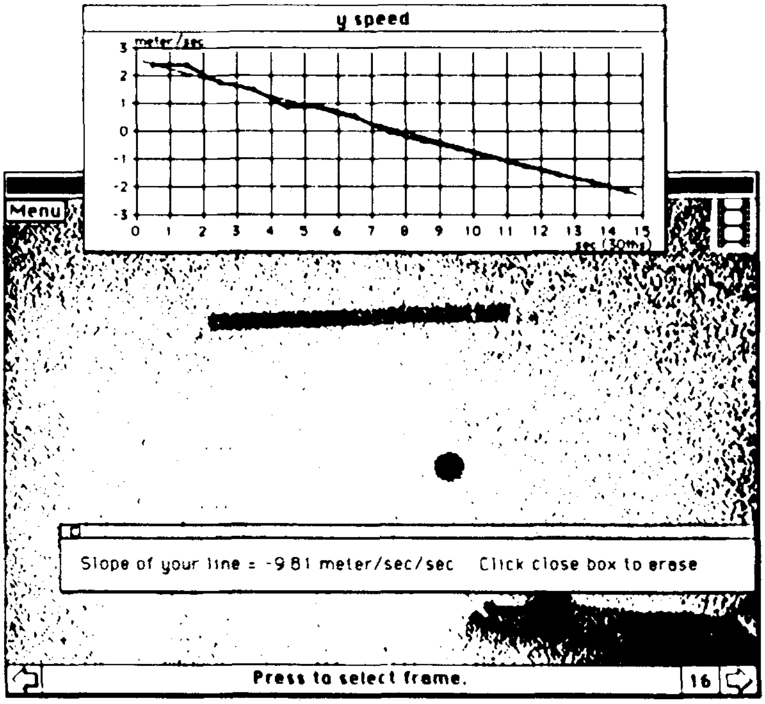
Besides the expectation of instructional effectiveness, there are several other advantages of the simultaneous VideoGraph display method. First of all, it raises possibilities for distance learning of kinematics material. Instead of requiring a student to be at the experimental site to gather data, the analysis and learning can be done in different, perhaps more convenient, surroundings. It is difficult to make a graph of an automobile's motion while standing at the side of the road, but it should be much easier to examine the motion while viewing a video display of the car. Although removing the student from "hands-on" involvement with the moving objects should probably not be carried to the extreme, it might be useful to be able to replay an interesting situation for closer study. Instructors could even distribute computer disks containing video images as components of homework problems. Additionally, the portability of the videocamera not only allows students to take measurements of moving objects in the laboratory but also lets them collect data from real-world events in precisely the same manner.

Because theory indicated we might have an effective variation on MBL techniques, and since there were additional advantages of the VideoGraph method, we decided that a study of its impact on graph understanding was worth pursuing.

A simple two-by-two design was employed. The first experimental factor was the type of laboratory experience-either VideoGraph or traditional methodology. The second dimension was whether the students viewed a real motion event or not. (There was also a group of students who were not exposed to any experimental treatment, but who took both the pre- and posttests.)

VideoGraph Environment

The computer software employed was custom written for this study (Beichner, 1989). The program allowed motion event reanimation and graph production to occur



Slope of your line = -9.81 meter/sec/sec Click close box to erase

Fig. 1. Sample Computer Screen Showing an Image and Graph

simultaneously. Before the graphs were produced and the animations performed, the students had to mark (with a mouse-controlled cursor) the position of a common point of interest on each individual frame. These points were some easily recognized feature of the object in motion and were used by the computer to generate coordinates and the graphs. Once this was done, students were able to examine position and speed graphs at their leisure. The students were able to replay the motion and graphs as many times as they liked, at normal or reduced rates of presentation, or they could stop the animation at any point. They could also use the computer to calculate the slope of any line they drew on the graphs or to determine the area under segments of the kinematics graphs. (See figure 1.)

Traditional Environment

The same type of projectile motion event was used by all groups. An object was thrown from lower left toward the upper right. The initial velocity was such that the object's path formed an arc across the field of view. Previously taken instant stroboscopic photographs served as the source of data for the conventional labs. The stroboscope was set to flash 30 times per second, essentially "freezing" the motion as often as the videocamera. The students were given very explicit instruction in how to make measurements from the photographs.

Experimental Treatments

All treatment sequences were directed through the use of worksheets guiding the students. All groups were told to examine the motion events and note the appearance of the graphs. They were also prompted to look for examples of situations where the graph changed in an unexpected manner. The activities of the traditional groups paralleled those of the VideoGraph students. The major difference between them was that the traditional groups had to produce their own data tables, construct graphs, and then calculate slopes and areas by themselves. For the most part, these tasks were done automatically for the VideoGraph groups, although they had to calibrate the computer measurements and indicate what parts of the graphs should be considered for slope and area determinations.

Groups which were to view a real motion event were shown a demonstration of projectile motion which was similar to that captured in the photographs and on the computer. Two separate times an object was thrown in a high arc across the classroom. Care was taken to ensure that no members of the other groups saw the motion event. Similarly, the computers were shown only to the VideoGraph groups. None of the students actually produced the motion events since they would have received kinesthetic feedback from the experience.

Since research (Carnes, Lindbeck & Griffin, 1987) indicates that several students working together learn more than individuals at microcomputers, and typical physics laboratory exercises have students work cooperatively anyway, students were assigned to teams of two to four people. Each VideoGraph team had access to its own computer. The members of each traditional team shared the duties of taking measurements, calculating values, and drawing graphs. Each individual had to sketch graphs (even if computer produced) and comment on their meaning.

Subjects

The experiment took place during the spring and fall of 1988. Entire physics classes from three western New York high schools, one local two-year college and an area four-year college participated in the experiment—a total of 237 students. The 165 high school students were mostly seniors with an average age of 17.4 years. The 72 college students had a mean age of 24.0 years. All students had received earlier kinematics instruction. The physics courses the students were enrolled in ranged from introductory level to engineering preparatory courses incorporating calculus.

Experimental Design

A balanced research design ensured that students from each school were represented in each treatment group. Students were randomly assigned to groups, but selected their own smaller working teams. A two-way analysis of covariance was performed on the posttest scores. Pretest results were used as the covariate. As noted earlier, the dimensions of the analysis were "technique" (VideoGraph or traditional) and "view" (actually witnessed a real motion event or did not).

Each group (except the Test Only students) took the pretest during a one-hour class session. Later, but within a week, they completed their graphing exercise during a regularly scheduled two-hour laboratory class. Finally, they completed the posttest during another one-hour session, again scheduled within a week of the laboratory. The Test Only students did not participate in any graphing activities. Both pre and post versions of the achievement test were taken during the same session, with a rest break between each test administration.

There were four experimental hypotheses. The first was that the groups using the computer for simultaneous viewing of motion images and the related graphs would show a higher mean score on the kinematics graph interpretation test than would the groups using the traditional stroboscopic analysis. This was based on the theory and findings cited earlier. The second was that groups which viewed motion events would have a higher mean score on the test than those groups which did not. We felt that seeing the actual event would make it easier to link concrete reality with the abstract graph. A third hypothesis dealt with an interaction; it was expected that there would be a greater difference between mean scores for the two traditional groups (differing in viewing or not viewing the motion event) than there would be between the two VideoGraph groups. In other words, if the animations were sufficient substitutes for reality, then the computer-using nonwitnesses should have less of a disadvantage than nonwitnesses who worked with static photographs. Finally, it was hypothesized that a comparison of overall pre- and posttest scores would show learning had occurred since all the lab exercises gave students an opportunity to work with kinematics graphs and their interpretation.

Performance Measure

The Test of Understanding Graphs—Kinematics (TUG-K) was constructed and validated prior to this study. Items were written for each of the eight objectives (Table I), producing a test of 24 multiple-choice questions. An effort was made to ensure that only kinematics graph interpretation skills were measured. For example, an item asking a student to "Select the graph which correctly describes the horizontal component of the speed of a projectile" would not be appropriate since it tests knowledge of projectile motion. The test measured only graph interpretation skills and did not have graph construction items on it. We did not want to confound our investigation of graph interpretation with construction tasks. (The area of graph construction skills certainly merits further study. Work by Adams and Shrum (1988) found that MBL students studying heat/cooling curves outperformed conventional students on graph interpretation but actually did worse on graph-construction tasks. It would be interesting to determine why one skill suffers while the other gains from MBL exposure.)

Many of the items had difficulty ratings much lower than one might expect from a well-designed test (Table II). In most cases, students would pick distractors suggested by commonly seen graphing misconceptions. In other instances, items were about topics which students should know, based on class syllabi. For example, any question requiring the interpretation of the area under a graph was missed by most students. Since we were looking for these types of problems, we did not rewrite the "harder" items in an effort to bring the item difficulties nearer to the ideal of 0.50. An unfortunate side effect of this decision is that items with extreme difficulty ratings must also have lower item discrimination indices (Doran, 1980). Nonetheless, after administration of the graphing test to 134 two-year college physics students, a KR-20 reliability of 0.71 was established, sufficient for the evaluation of groups. Including students from this study gave KR-20 reliabilities of 0.73 ($N = 256$) and 0.78 ($N = 240$) for the pre- and

TABLE I
Objectives of the Test of Understanding Graphs—Kinematics

	Given:	The student will:
Coordinates		
1.	A set of coordinates	locate the point on a graph
	A point on a graph	select the corresponding coordinates.
Relationships between Kinematic Variables and Graphs		
2.	A position-time graph	deduce the speed at any instant.
3.	A speed-time graph	deduce the acceleration at any instant
4.	A speed-time graph	deduce the displacement.
5.	An acceleration-time graph	deduce the change in speed.
6.	Any kinematics graph	select one of the two corresponding graphs
Relationships Between Motion and Graphs		
7.	Any kinematics graph	select an appropriate motion description
8.	A description of motion	select a corresponding graph.

posttest, respectively. There were no significant practice effects between pre- and posttest administrations.

Results

Since ANCOVA statistics are somewhat less robust than the corresponding ANOVA statistics, it is especially important to verify that the assumptions involved are satisfied. An examination of the data revealed that all assumptions were met.

Based on an analysis of the pretest scores, there were not significant differences between students assigned to the different groups $F\ (3, 218) = 0.775$, $p = 0.509$ (Table III). Although the highest posttest scores were made by the MBL students, the statistical analysis with the pretest as covariate found no significant main effects and no interaction, as detailed in Table IV. This finding was contrary to three of the original hypotheses. On the other hand, a paired samples t-test of pre- and posttest scores ($t = 4.86$, $df = 221$, $p < 0.001$) indicated that there was significant learning overall, as predicted by the fourth hypotheses.

Table V shows that males scored significantly higher than females on both the pretest, $F\ (1, 219) = 4.89$, $p = 0.028$, and the posttest, $F\ (1, 219) = 6.07$, $p = 0.015$. Becker (1989), in a combination of metaanalyses, notes that males generally perform better on science achievement tests. This difference is seen to be due to a combination of factors including the fact that students view science as masculine (Vockell & Lobonc, 1981) and that the sexes receive differential treatment and expectations from teachers (Brophy & Good, 1970). In our study, neither gender learned more

TABLE II
Test of Understanding Graphs—Kinematics Item Analysis

Item Number	Objective	Difficulty		Discrimination	
		Pre	Post	Pre	Post
1	4	.73	.85	.36	.21
2	2	.13	.63	.16	.40
3	7	.92	.90	.14	.07
4	3	.75	.54	.20	.51
5	4	.32	.35	.38	.41
6	1	.93	.89	.13	.12
7	7	.53	.51	.41	.47
8	3	.28	.40	.34	.48
9	7	.31	.52	.45	.50
10	8	.15	.39	.30	.36
11	1	.91	.89	.11	.14
12	5	.07	.11	.10	.07
13	6	.25	.31	.26	.38
14	8	.53	.29	.48	.37
15	1	.97	.86	.04	.11
16	2	.95	.95	.09	.07
17	5	.07	.10	.13	.16
18	6	.27	.40	.22	.39
19	8	.60	.70	.13	.04
20	2	.52	.65	.26	.25
21	6	.42	.43	.39	.42
22	5	.14	.13	.16	.15
23	3	.86	.64	.13	.32
24	7	.47	.44	.18	.20

than the other, as evidenced by an analysis of the difference between pre and posttest scores (the change score), $F(1, 219) = 0.84, p = 0.36$.

As might be expected, the pretest and posttest scores varied substantially by school, $F(3, 218) = 8.30, p < 0.001$, but there was no significant difference in the change score between schools, $F(3, 218) = 0.31, p = 0.82$. See Table VI. College students learned as much from the graphing lab exercises as high school students.

After the posttest, 55 college students were shown the four different treatments that were being examined (computer or traditional, witness motion or not) and then they were given an affect questionnaire. When asked to pick the technique they would rather use for any other kinematics labs they might have to perform, 44 students picked the VideoGraph technique as their first choice. This was not to the exclusion of viewing the motion, however. Students felt that it was more important to witness the motion event than to watch it on a computer screen. 51 selected as their top choice either the VideoGraph or traditional techniques which allowed witnessing of the motion.

TABLE III
Student Scores

	Traditional		MBL			Total
	View motion Mean/s.d.	Did not view Mean/s.d.	View motion Mean/s.d.	Did not view Mean/s.d.	No Lab Mean/s.d.	Experimental Mean/s.d.
n	51	58	58	55	15	222
Pretest (24 items)	11.5/3.7	12.2/3.8	12.3/3.4	12.5/3.5	12.8/3.5	12.2/3.6
Posttest (24 items)	12.3/4.3	13.4/4.4	12.7/4.0	13.5/4.0	13.2/4.5	13.0/4.2

Discussion

This study looked at the educational impact of the visual juxtaposition of a motion event with kinematics graphs. The main hypothesis stated that merely seeing a recreation of the event in the form of a computer animation of videotaped images should be sufficient to let students learn significantly more than the traditional kinematics lab experiments allowed. This did not prove to be the case. Although the VideoGraph students had higher scores than did the traditional groups, this difference was not large enough to be statistically meaningful. There was also no significant difference between groups which witnessed the motion and those that did not. This may be due to the fact that the motion was that of a simple (i.e., commonly seen) projectile trajectory. If a more complex event were studied, one with which the students would not already be familiar, there may be a significant advantage in being a member of a motion-witnessing group.

An examination of what students do during kinematics MBL experiences shows that they see the motion event while the graph is being produced. They also actively control what appears on the graph by adjusting the motion event. This study indicates that it may be this second aspect of MBL that makes the difference. The VideoGraph

TABLE IV
Analysis of Covariance

Source	Sum of Squares	*df*	Mean square	*F*	*p*
Viewed	19.2	1	19.16	2.91	0.090
Treatment	5.37	1	5.37	0.82	0.368
Viewed X Treat	0.003	1	0.003	0.00	0.984
Pretest	2412.18	1	2412.18	366.00	0.000
Error	1430.17	217	6.591		

TABLE V
Pretest and Posttest Summary by Gender

	Female		Male	
	Mean	s.d.	Mean	s.d.
n	84		137	
Pretest	11.5	3.3	12.6	3.7
Posttest	12.1	3.8	13.5	4.4

technique can present replications of motion events while generating graphs, but other than determining the rate of animation, students cannot control the motion. This ability to make changes—and then instantly see the effect—is vital to the efficacy of microcomputer-based kinematics labs. The feedback appeals to the visual and kinesthetic senses. A simple visual juxtaposition of event images and graphs is not as good as seeing (and "feeling") the actual event while graphs are being made.

A direct comparison of the VideoGraph technique with the real-time graphing of the sonic ranging MBL developed at the Technical Education Research Centers (TERC) would allow for further exploration of the nature of real-time data collection versus a video presentation of the event. It would be interesting to vary the amount of control students have (none, as in a demonstration; some, by giving verbal directions, complete, they themselves cause the motion) and see how this impacts learning. This would also ensure that all groups examined the same motion events. Students in Brasell's study actually looked at a variety of physical situations, including trying to create motion that matched a given graph. This may have led to the significant improvement over traditional labs. Also, it might be important to have the traditional lab groups perform the same types of analyses since this could have an impact on how well they perform. In this study, the students who worked on the conventional tasks were heavily involved with their data. Substantial calculational effort was required. This may have been the reason for their sizable improvement from the pretest to the posttest. Research to compare sonic MBL to VideoGraph directly should require the same non-computer tasks.

TABLE VI
Pretest and Posttest Summary by School

	College		High School A		High School B		High School C	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
n	51		58		58		55	
Pretest	12.5	4.3	10.0	2.7	13.3	3.0	12.2	3.3
Posttest	13.4	4.9	11.0	3.6	14.3	3.5	12.8	4.1

to compare sonic MBL to VideoGraph directly should require the same non-computer tasks.

A direct comparison study would also standardize the measure of achievement. In the Mokros and Tinker (1987) examination of the sonic ranger MBL, many of their test items related to moving people. This makes it easier for students to relate to their lab experience, but the results may not be generalizable to testing an understanding of the motion of other objects. The TUG-K items are being revised for use in further studies since the achievement gains seen in this study were not much different than the standard error of measurement for the test (approximately 1.9). We also found that only slight changes in wording affected student scores. Future versions of the TUG-K should more closely approximate parallel tests.

The VideoGraph students did not perform significantly better than the traditional laboratory, at least after a single lab period exposure, although there was a trend for them to have higher scores. An extended study of the VideoGraph technique might demonstrate superiority over conventional instruction. This has important implications for the use of simulations in the classroom. Since the VideoGraph students—even those who witnessed a motion event—did not see the actual event which was videotaped, they were essentially working with a simulation. This study shows then, that at least in this single-exposure situation, a simulation is no better than traditional lab experience. It was noted that the computer-using students finished their tasks substantially faster than their conventional counterparts. If this time were used for an evaluation of additional motion situations, then students taking advantage of this might very well perform better than those taking traditional labs. Students seemed more willing to examine different parts of their graphs in the computer-using groups, if only because it was trivial to calculate a different slope or find a new area.

Since the VideoGraph technique depends so heavily on the screen display, it might be important to find the best sorts of screen layout. For example, does displaying more than one graph at a time result in distraction and hence a further reduction in educational effectiveness or does it allow for easier comparisons? This would be fairly easy to examine using the custom software developed for this study. The quality of the VideoGraph images also left much be desired. Perhaps students would relate better to sharper, color pictures and smoother animations. The technology is now available to test this, but costs are quite high.

The kinesthetic sense is a strong one and appears to make a difference in kinematics MBL's. Perhaps other areas of student investigation would not have as great a requirement for real-time data collection and display. A comparison of other (non-kinematics) MBL labs to those using videodisk images of reactions taking place versus student-controlled titrations, heating, etc., might be informative.

Acknowledgments

This work was supported by a grant from the National Science Foundation (No. CSI-8750443). Apple Computer, Inc. generously supplied hardware for the project. Dr. Michael DeMarco, Dr. David Ettestad, and Mr. Edward Gleason of the SUNY College at Buffalo were extremely helpful during the research effort. Dr. S. David Farr and Mr. Ronald Vullo of the Center for Learning and Technology at SUNY/Buffalo supported the research efforts beyond all reasonable expectations. Finally, I would like to mention my appreciation for the help and encouragement of Dr. Rodney Doran of the Department of Learning and Instruction at SUNY/Buffalo.

References

Adams, D., & Shrum, J. (1988). The effects of microcomputer-based laboratory exercises on the acquisition of line graph construction and interpretation skills by high school biology students. Paper presented at the Sixty-First Annual Meeting of the National Association for Research in Science Teaching, Lake of the Ozarks, MI, April, 1988.

Adams, E.N. (1965). "Roles of the computer in university instruction." In *Report on the Conference on the Uses of the Computer in Undergraduate Physics Instruction*, Irvine, CA: The Commission on College Physics, pp. 1–5.

Barclay, W.L. (1986). Graphing misconceptions and possible remedies using microcomputer-based labs. Paper presented at the Seventh National Educational Computing Conference, San Diego, CA, June, 1986.

Becker, B. (1989). Gender and science achievement: a reanalysis of studies from two meta-analyses. *Journal of Research in Science Teaching*, **26**, 141–169.

Beichner, R.J. (1989). *VideoGraph* [Computer program]. Buffalo, NY: Center for Learning and Technology, SUNY at Buffalo.

Bell, A., Brekke, G., & Swan, M. (1987). Misconceptions, conflict, and discussion in the teaching of graphical interpretation. Paper presented at the Second International Seminar in Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, NY, July, 1987.

Brasell, H. (1987). The effect of real-time laboratory graphing on learning graphic representations of distance and velocity. *Journal of Research in Science Teaching*, **24**, 385–395.

Brophy, J. & Good, T. (1970). Teachers' communication of differential expectations for children's classroom performance: Some behavioral data. *Journal of Educational Psychology*, **61**, 365–374.

Carnes, E., Lindbeck, J. & Griffin, C.F. (1987). Effects of group size and advance organizers on learning parameters when using microcomputer tutorials in kinematics. *Journal of Research in Science Teaching*, **24**, 781–789.

Clement, J., Mokros, J.R. & Schultz, K. (1986). Adolescents' graphing skills: a descriptive analysis. Paper presented at the annual meeting of the American Educational Research Association, April, 1986.

Doran, R. (1980). *Basic Measurement and Evaluation of Science Instruction*. Washington, D.C.: National Science Teachers Association.

Hulse, S., Egeth, H. & Deese, J. (1980). *The Psychology of Learning*, 5th ed. New York: McGraw-Hill.

Linn, M., Layman, J. & Nachmias, R. (1987). Cognitive consequences of microcomputer-based laboratories: graphing skills development. *Contemporary Educational Psychology*, **12**, 244–253.

Lockhead, J. (1980). The confounding of cause and effect, change and quantity. In J. Robinson, Ed., *Research in Science Education: New Questions, New Directions*. Louisville, CO: Center for Educational Research and Evaluation, pp. 73–84.

McDermott, L., Rosenquist, M. & van Zee, E. (1987). Student difficulties in connecting graphs and physics: examples from kinematics. *American Journal of Physics*, **55**, 503–513.

Mokros, J. & Tinker, R. (1987). The impact of microcomputer-based labs on children's ability to interpret graphs. *Journal of Research in Science Teaching*, **24**, 369–383.

Niedderer, H. (1987). Alternative framework of students in mechanics and atomic physics: methods of research and results. Paper presented at the Second International Seminar in Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, NY, July, 1987.

Perry, B. & Obenauf, P. (1987). The acquisition of notions of qualitative speed: the importance of spatial and temporal alignment. *Journal of Research in Science Teaching*, **24,** 553–565.

Reed, S. & Saavedra. N. (1986). A comparison of computation, discover, and graph procedures for improving students' conception of average speed. *Cognition and Instruction*, **3,** 31–62.

Shuell, T. (1986). Cognitive conceptions of learning. *Review of Educational Research*, **56,** 411–436.

Thornton, R. (1986). Tools for scientific thinking: microcomputer-based laboratories for the naive science learner. Paper presented at the Seventh National Educational Computing Conference, San Diego, CA, June, 1986.

Thornton, R. (1988). Tools for scientific thinking: learning physical concepts with real-time laboratory measurement tools. Paper presented at the Conference on Computers in Physics Instruction, Raleigh, NC, July, 1988.

Tinker, R. (1986). *Modeling and MBL: software tools for science*. Paper presented at the Seventh National Educational Computing Conference, San Diego, CA, June, 1986.

van Zee, E., & McDermott, L. (1987). Investigation of student difficulties with graphical representations in physics. Paper presented at the Second International Seminar in Misconceptions and Educational Strategies in Science and Mathematics, Ithaca, NY, July, 1987.

Vockell, E. & Lobonc, S. (1981). Sex-role stereotyping in high school females in science. *Journal of Research in Science Teaching*, **18,** 209–219.

Manuscript accepted November 6, 1989.