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The influence of interactive videodisc instruction using real-time analysis on kinematics graphing skills of high school physics students

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Kansas State University, 1993

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THE INFLUENCE OF INTERACTIVE VIDEODISC INSTRUCTION USING REAL-TIME ANALYSIS ON KINEMATICS GRAPHING SKILLS OF HIGH SCHOOL PHYSICS STUDENTS

by

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B.A., Benedictine College, 1980
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A DISSERTATION

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requirements for the degree

DOCTOR OF PHILOSOPHY

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Abstract

This study investigated student understanding of kinematics graphing skills by comparing real-time and delay-time graphing of the motion of objects which were displayed by a videodisc. Previous research has demonstrated mixed results regarding the use of real-time graphing (when a kinematics graph is produced on the computer screen *simultaneously* with the motion of an object) compared to the use of delay-time graphing (when a kinematics graph is produced on the computer screen *after* the student has watched the motion of an object). This study used a greater treatment time, utilized qualitative data analysis more fully than the other studies, and employed interactive videodisc instruction to provide further insights into the real-time effect.

Thirty-one high school physics students were randomly assigned to either a real-time experimental group or a delay-time contrast group. Students working in lab groups of two performed four laboratory exercises over a three-week treatment period, and then took a posttest on kinematics graphing. Interviews were given at the end of each treatment, and retention interviews were given to selected students three weeks following the posttest. All interviews were videotaped.

The main hypothesis stated that students would achieve significantly better understanding of kinematics graphing if real-time graphing was used instead of delay-time graphing. The hypothesis was not supported. However, evidence was found that suggests that the real-time effect may have some advantages in five areas: a) real-time students were aware of the real-time effect, and seemed motivated by it, b) real-time students decreased their eye movement between computer screen and video screen as subsequent graphs were produced, c) real-time students demonstrated more discussion during graphing than delay-time students, d) real-time students displayed less confusion between velocity versus time and acceleration versus time graphs than delay-time students, and e) real-time students did not attend to minor fluctuations in graphs as much as delay-time students.

Chapter I—Introduction

Background

"This is a time of ferment in physics teaching" (Wilson, 1989, p. 94). Much effort in the past decade has centered on improving physics instruction at all levels, with discussion including such topics as "computers in physics, research in physics education (cognition), and incorporation of modern physics into the curriculum" (Wilson, 1989, p. 94). A topic much debated at the introductory level is that "problems treated in our courses are simple and unrealistic and not treated with an awareness of cognitive issues" (Resnick, 1988, p. 75). Students see many physics laboratory exercises as contrived and not applicable to everyday life. Sadanand and Kess (1990) posited that "perhaps not enough time is spent analyzing more realistic examples that show how the physical principles we learn can be used to explain such phenomena" (p. 533). As a result, students' attitudes toward physics and physics laboratories decline.

With only 20% of high school graduates having taken a physics class (Neuschatz & Covalt, 1988, p. 4), much should be done to improve the interest of students toward physics. Improving attitude toward physics will help increase enrollment in this essential science, a discipline that is extremely valuable in an increasingly technological world. New instructional technologies, such as microcomputer-based laboratories and interactive videodisc instruction, could boost interest in the subject by providing more realistic examples of physical phenomenon to investigate.

Many have hypothesized reasons for this lack of enrollment in physics. One reason under scrutiny is that students do not understand the symbolism of physics; for example, they remain uncertain about the symbolic representation of kinematics situations by graphical techniques. Research begins to show that technology could be used to assist students in improving their understanding of the symbols and languages of physics. Hopefully, this process will also increase enrollment in physics.

Physics misconceptions and graphing skills

The physics content area involved in this study is kinematics, specifically the graphical skills needed to analyze kinematics data. Knowledge of graphing techniques in general is "important for the development of scientifically literate individuals" (Padilla, McKenzie, & Shaw, 1986, p. 20). Leinhardt, Zaslavsky, and Stein (1990) said that "graphs serve as representations of real observations and as analytic tools for detecting underlying patterns" (p. 20).

Currently, many physics students lack skills in recognizing the physical significance of a graph, both in seeing graphs as just pictures, and in confusing slope with height (Mokros & Tinker, 1987). Students also have misconceptions concerning the graphical representation of negative velocity (Goldberg & Anderson, 1989), and of acceleration (McDermott, Rosenquist, & van Zee, 1987). In addition, McDermott et al. found that students had "difficulty in connecting graphs to physical concepts and difficulty in connecting graphs to the real world" (1987, p. 503). Thus, much research is needed to find ways to assist students with learning the important concept of graphical analysis.

Microcomputer-based laboratory

Microcomputer-based laboratory (MBL) tools consist of a computer interfaced with an input device, software, and courseware. The computer can analyze data provided by the input device. For example, researchers at the Technical Education Research Center (TERC) have designed an experiment in which a student walks in front of a sonic motion detector. The computer analyzes the signal and displays a kinematics graph simultaneously with the motion. Researchers have measured significant improvements in student learning of graphical skills by using the ability of MBL tools to produce such real-time graphs (Brasell, 1987a; Mokros & Tinker, 1987).

Interactive videodisc instruction

Interactive videodisc instruction provides a technique for presenting everyday-life situations to be studied by physics students. For example, the Physics of Sports videodisc (Noble & Zollman, 1988) contains hundreds of examples of people performing athletic events. Each event has been videotaped with measuring devices in the background. Students can record data directly from the video screen while playing the videodisc. One example consists of an archery sequence where an archer draws back a bow. The change in force is determined with a spring scale, the change in displacement is determined with a grid behind the bow, and the time is displayed in the corner of the screen. A student can view the archery sequence by a computer-controlled, frame-by-frame search, and record force, displacement, and time data.

Using an interactive videodisc system, students analyze data that they will see once outside the physics laboratory. Hopefully, this will preclude students from developing the insight that physics did not apply "anywhere other than the strict confines of the physics classroom" (Van Hise, 1988, p. 498).

Definitions

delay-time graphing: when a kinematics graph is produced on the computer screen *after* the student has watched the motion of an object. In this project, the time delay between motion and graphing was a few minutes. The object may be an object in the laboratory, a videotaped object seen on a video monitor, a simulated object seen on the computer monitor, or a digitized motion re-animation of an object seen on a computer monitor.

interactive videodisc instruction: using a videodisc system to instruct a student by having the student take data from the video, answer questions determining which video will be shown, or in some way interact with the videodisc system.

interactive videodisc system: videodisc, videodisc player and monitor, interface, computer and monitor, software and courseware that allow a teacher or student to use interactive videodisc instruction.

kinematics: the study of motion, including such topics as displacement, velocity, acceleration, and time.

kinesthetic laboratory: a laboratory exercise in which the student's self-motion is the object of study, instead of the motion of a ball or other inanimate object.

MBL: microcomputer-based laboratory. This consists of a laboratory exercise in which a microcomputer system, interface, transducer, and software are used to collect, analyze, store, and display data.

real-time graphing: when a kinematics graph is produced on the computer screen *simultaneously* with the motion of an object. The object may be an object in the laboratory, a videotaped object seen on a video monitor, a simulated object seen on the computer monitor, or a digitized motion re-animation of an object seen on a computer monitor.

Statement of problem

The research cited above indicates that (1) physics students at the introductory levels have a poor understanding of kinematics graphing, (2) a significant improvement in the understanding of kinematics graphing has been achieved by real-time graphing with microcomputer-based laboratory tools and (3) interactive videodisc instruction provides real-world connections to physical phenomenon. The proposed research will focus on a combination of these components and investigate if real-time graphing with interactive videodisc instruction will improve understanding of kinematics graphing.

Hypotheses

The quantitative hypothesis to be tested is:

> Students will achieve significantly ($p<.05$) better understanding of kinematics graphing, as measured by a posttest, with the use of real-time graphing as part of interactive videodisc instruction when compared to delay-time graphing as part of interactive videodisc instruction.

The qualitative hypothesis to be tested is:

> Students who use real-time graphing as part of interactive videodisc instruction will have significantly fewer misconceptions about kinematics graphing, as determined by an analysis of written work and oral comments, than students who use delay-time graphing as part of interactive videodisc instruction.

Limitations

The generalization of this research to the population of high school physics students will be questionable, since the sample was not randomly selected from the broader population of high school physics students. Secondly, this sample consisted of an elective physics class in a private high school, so generalization to public high school students is questionable. However, the academic backgrounds of both of these types of students are similar, since most students had taken biology, chemistry, Algebra I and geometry before physics class. This research should be repeated in a public high school, or on a random population of high school physics students. Also, a larger sample size would increase the statistical validity of this research.

Chapter II—Review of the Related Literature

Physics misconceptions and graphing skills

Physics students have many misconceptions that they bring to the classroom. Brown (1992) used "the term 'misconception' to refer to students' ideas which are incompatible with currently accepted scientific knowledge" (p. 17). McDermott and Shaffer (1992) used "misconception" to mean "an idea for which the student's interpretation is in conflict with the formal concept as understood by a physicist" (p. 1002). Others have used descriptors such as "naive theories" (McCloskey, 1983, p. 299), or "alternate conceptions" (Dykstra, Boyle, & Monarch, 1992, p. 615) to describe these incompatible or conflicting ideas. However, Brown (1992) noted that

> these conceptions should be respected as creative constructions of the individual which in many cases are adaptive and successful for dealing with the practical world. These naive conceptions do, however, present significant barriers to learning a subject like Newtonian mechanics and as such need to be addressed as difficulties from the perspective of the content domain being taught. (p. 17)

The Physics Education Group at the University of Washington has completed research to understand better students' misconceptions in physics. Some of the work has concentrated on misconceptions and difficulties with graphing in kinematics. McDermott et al. (1987) categorized ten difficulties students had in graphing of kinematics:

Difficulties in connecting graphs to physical concepts:
A. Discriminating between slope and height
B. Interpreting changes in height and changes in slope
C. Relating one type of graph to another
D. Matching narrative information to graph
E. Interpreting the area under a graph

Difficulties in connecting graphs to the real world:
A. Representing continuous motion by a continuous line
B. Separating the shape of a graph from the path of the motion
C. Representing negative velocity
D. Representing constant acceleration
E. Distinguishing between different types of motion graphs

These findings were gathered from student pencil/paper constructed graphs, or else from narrative information with a graph already provided.

Halloun and Hestenes (1985) developed a "taxonomy of common sense concepts about motion," (pp. 1063-1064) which included kinematics and mechanics, to assist physics teachers with instruction. Similarly, Minstrell and Stimpson (1986) developed a framework for dealing with student conceptions in mechanics.

Mokros and Tinker (1987) found "a strong tendency among students to view graphs as pictures rather than as symbolic representations" (p. 371). For example, a bicyclist's speed versus time graph over a series of hills is drawn as a picture of the hills. Many students believe that the point of maximum cooling on a temperature versus time graph corresponds to the lowest point on the graph.

Students have a cognitive difficulty with negative velocity because students do not connect negative displacements or velocities with their everyday experience. For example, observations that students make of an odometer or speedometer give them only a "positive" sense of displacement and velocity. Thus, they actually observe only distances and speeds in nature. However, then they are asked to use the words "displacement" and "velocity" in physics class, this time in a vector context. For example, the speedometer does not read +20 mph when moving east and -20 mph when moving west, yet the physics teacher insists that east is positive and west is negative. Goldberg and Anderson (1989) also speculated that students believe negative means "a lesser quantity" or "losing something" (p. 258). Thus, students have difficulty with the graph of an object rolling up a hill, coming to a stop, then rolling down the hill. How can the object have less velocity than the zero velocity at the highest point of motion? Karplus (1977) pointed out in his learning cycle that students must explore their environment to experience physical phenomena and the patterns that govern that phenomena. When their observations outside the classroom seems to conflict with their instruction inside the classroom, however, students have difficulty learning.

Linn, Layman, and Nachmias (1987) argued that students can process only a limited amount of information at a time. This cognitive capacity can be "overloaded" if there are too many concepts at once, and especially if the concepts are conflicting, such as school physics concepts conflicting with the student's world view of a phenomenon. They posited a "chain of cognitive accomplishments" that is "an ideal sequence of cognitive accomplishments culminating in a desired skill" (p. 246) for graphing. For example, graphical interpretation has a "graph template" as one part of its chain. Here students form a prototype of a particular phenomenon, and then use that template for fitting a new situation into their world view (p. 247). A possible reason for the success of microcomputer-based laboratories is that they facilitate the forming of graph templates since many graphs can be viewed easily in real-time.

Microcomputer-based laboratory

Experimental studies of microcomputer-based laboratory tools are occurring in many locations. Robert Tinker and his colleagues at TERC pioneered the use of MBL materials in the introductory physics classroom. Thornton (1987) speculated that MBL tools assist students in learning physics concepts and skills by extending the range of student investigations, providing immediate feedback of graphs in real-time, encouraging critical thinking, and reducing laborious manual data collecting and analysis. Thornton and Sokoloff (1990) further reported on the efficacy for college students of MBL instruction as compared to traditional lecture/problem solving approaches to physics. They pointed out that "MBL tools give students the opportunity to do real science" by "the creative building and testing of models to explain the world around them" (p. 865), and by understanding "the specific and familiar before moving to the more general and abstract" (p. 866).

Brasell (1987a) demonstrated that high school physics students had significantly better understanding of distance and velocity graphs when viewing the motion in real-time with the appearance of the graph, as compared to delay-time graphing. A single laboratory period was used as a treatment, and students showed significantly fewer learning gains with as little as a 20-30 second delay of displaying the data. She posited that this time "placed an additional information-processing demand on the students" (p. 393), which led to less understanding. In addition, Brasell found real-time MBL students to be more motivated.

Mokros and Tinker (1987) found positive results with middle school students using MBL tools to assist learning of graphing concepts. They suggested four reasons why MBL materials assist students in learning: "MBL uses multiple modalities; it pairs, in real-time, events with their symbolic representation; it provides genuine scientific experiences; and it eliminates the drudgery of graph production" (p. 381). One of the modalities is the use of the student's own body as the object of motion study. This kinesthetic aspect is discussed below.

Adams and Shrum (1990) found mixed results regarding the use of MBL materials to assist students with graph construction and interpretation. High school students who used conventional laboratories demonstrated higher achievement on graph construction tasks than MBL students. However, MBL students had higher achievement in graph interpretation tasks.

Regarding gender differences and real-time analysis, Brasell (1987b) found that "after separating the results for each treatment and controlling for differences in covariates, there were significant sex differences on the kinematics posttest for students in the standard-MBL treatment" (p. 106). She found that females scored significantly higher on distance items, while males scored significantly higher on velocity items. She did state, however, that due to the short treatment time used (one class period), that "rather than provide answers, these results define questions to be addressed in future research" (p. 111). Beichner (1990) found no gender differences in the real-time effect.

Interactive videodisc instruction

Little is known about the efficacy of interactive videodisc instruction in science education. Descriptive studies in physics (Davis, 1985), biology (Lehman, 1985), and chemistry (Brooks, Lyons, & Tipton, 1985) are available. Experimental studies have been reported in physics (Stevens, 1984), biology (Leonard, 1989, 1992), earth science (Vitale & Romance, 1992), and chemistry (Stevens, Zech, & Katkanant, 1988; Savenye & Strand, 1989). These studies typically showed high student interest in videodisc instruction. No evidence has been found that shows the efficacy of interactive videodisc instruction in graphical skills.

An interactive videodisc system can also produce a graph in real-time with the motion of an object, like a MBL system. However, with a videodisc, the object is seen on the video screen; the object is not being observed in a hands-on laboratory experience. One factor that might have assisted MBL students to comprehend graphs is the manipulative nature of its hands-on laboratory environment (Brasell, 1987a). The student *was* the object under investigation in the motion detector laboratories, so the students were involved with their own Bloom's psychomotor domain, not just the cognitive and affective domains. Beichner (1990) and Mokros and Tinker (1987) surmised that the kinesthetic feedback of MBL materials is one component that contributes to its success in kinematics studies. Videodisc instruction cannot give this component; thus, it would be informative to see if real-time graphing via videodisc instruction does improve understanding without the manipulative component.

Beichner's (1990) study included real-time graphing, but it was not based on either a MBL or a videodisc. Instead, he used "the recreation of the event in the form of a computer animation of videotaped images" (p. 803). He found that students using this technique did not have significant learning gains as compared to traditional instruction. He surmised that the real-time effect was "not the relevant variable producing the educational impact of real-time MBL" (p. 803).

Summary

The evidence that MBL tools are effective in improving physics learning is compelling. However, the reasons why MBL materials are effective is unclear. Brasell's (1987a) research suggested that the real-time nature of a MBL is a critical feature, but Beichner's (1990) study with motion reanimation concluded that real-time is not a critical variable. Both studies drew evidence from a one-class period treatment. In addition, no long-term retention data were taken by either of these studies. Research that includes an extended treatment period, that uses an interactive videodisc system to produce real-time graphs, and that has a retention component, would provide evidence that might clarify this topic.

Chapter III—Methodology

Introduction

The question that emerges from the research data is: Why does the use of MBL tools seem to increase students understanding of kinematics graphs in comparison to students who receive traditional instruction? Researchers have hypothesized that several factors are involved:

1. The real-time nature of a MBL—seeing the graph simultaneously with the motion of the object.
2. The kinesthetic nature of a MBL—students getting their entire body movement involved in motion studies, not just their eyesight and mind.
3. The ability of MBL tools to present dozens of graphs per class period, thus providing the graphs of many physical situations per time.

The ability of MBL tools to present many graphs is intuitively an advantage, since repetition is helpful to learning. No literature has been found that has investigated limiting the number of graphs per time produced by a MBL to see if repetition is the critical factor in the success of MBL materials.

The kinesthetic nature of MBL tools has also not been investigated. For example, no literature has been found that has compared a *person* walking toward a sonic ranger to a *cart* rolling toward a sonic ranger.

The real-time nature of MBL materials has been investigated by Brasell (1987a), but with only one laboratory period treatment. Similarly, the real-time nature of video-recorded and digitized graphics has been investigated by Beichner (1990); again, only for a single laboratory period.

This study looked further into the display of kinematics graphs in real-time by using an interactive videodisc system. Thus, this research was similar to Beichner (1990), by attempting to isolate the real-time variable. In addition, this research investigated kinematics for a three-week treatment time, with four laboratory exercises, in a naturalistic classroom environment. Also, retention interviews were given to determine long-term learning gains. This study did not test the kinesthetic nature involved in a physics laboratory, since the event is from a videodisc. In addition, it did not allow repetition during each laboratory period, since data are collected by students and analyzed for one event at a time.

Student sample

The thirty-one high school students in this study were enrolled in a general physics class at a private high school. Thirty students were in twelfth grade and had already completed biology and chemistry. One student was in tenth grade, concurrently enrolled in biology, and had not taken chemistry. Previous to the research, all students had completed Algebra I, all but three students had completed Algebra II, all but one student had completed geometry, and 12 students had completed trigonometry (a one semester course at this school). During the research semester, students were concurrently enrolled in Algebra II, trigonometry, calculus, or no math class. Students and their parents completed informed consent forms. Grades were not given for student participation or non-participation in this project. The students were randomly assigned to the experimental group and to the contrast group. The units of analyses were the individual and the laboratory group of two. One student was dropped from the study due to a two-week absence in the middle of the treatment period.

Laboratory exercises

The students performed four kinematics laboratory exercises, each of increasing conceptual difficulty, over a three-week period using an interactive videodisc system. In each laboratory, they observed a motion sequence of a sporting event on a video monitor. Next, they collected, by hand, displacement data of the object in the event, and entered the data into a spreadsheet. The computer then calculated velocity and acceleration values, plotted the displacement versus time graph, the velocity versus time graph, and finally the acceleration versus time graph on the computer screen.

Independent variable

The experimental group, the real-time group, viewed the motion of the object on the video monitor simultaneously with the drawing of the displacement versus time graph on the computer monitor. Similarly, the drawing of the velocity versus time graph was shown simultaneously with the motion of the object. Finally, the drawing of the acceleration versus time graph was displayed simultaneously with the motion of the object.

The contrast group, the delay-time group, viewed the same graphs, but the graphs were drawn on the computer monitor several minutes after the completion of the motion sequence on the video monitor. The graphs were drawn at the same rate as the real-time group; thus, the only difference was whether the students saw the graphs being drawn simultaneously with the event, or the graph being drawn after the event. Students from either group could review any of the information presented by the videodisc system at any time.

Courseware

Software was written for this investigation. The software controlled a videodisc player and displayed instructions and information on the computer screen concerning the use of the videodisc system, including navigating the software, sending commands to the videodisc player, collecting data, entering data into the computer, calculating velocity and acceleration, and graphing. Screen dumps of the software, and sample computer graphs of the kinematics data, are found in Appendix A. The Physics of Sports videodisc (Noble & Zollman, 1988) was used to present four scenes of sporting events representing four types of motion, each of increasing complexity:

1. One-dimensional, constant velocity, the distance runner: This scene shows a race between a distance runner and a sprinter. Students were instructed to only analyze the distance runner's motion.

2. One-dimensional, non-zero, horizontal acceleration, the skilled sprinter: This screen shows a sprinter in a starting block accelerating from rest.

3. One-dimensional, non-zero, vertical acceleration, the cheerleader: This scene shows a cheerleader being pushed almost straight upward by two yell leaders, turning a flip, descending, and being caught. The motion is predominantly vertical, although there is a slight horizontal motion.

4. Two-dimensional, non-zero, vertical acceleration, the basketball: Here, the motion studied is not that of the athlete, but of a basketball during a free throw. Example graphs of this motion, as generated by the computer, are shown in Figure 1.

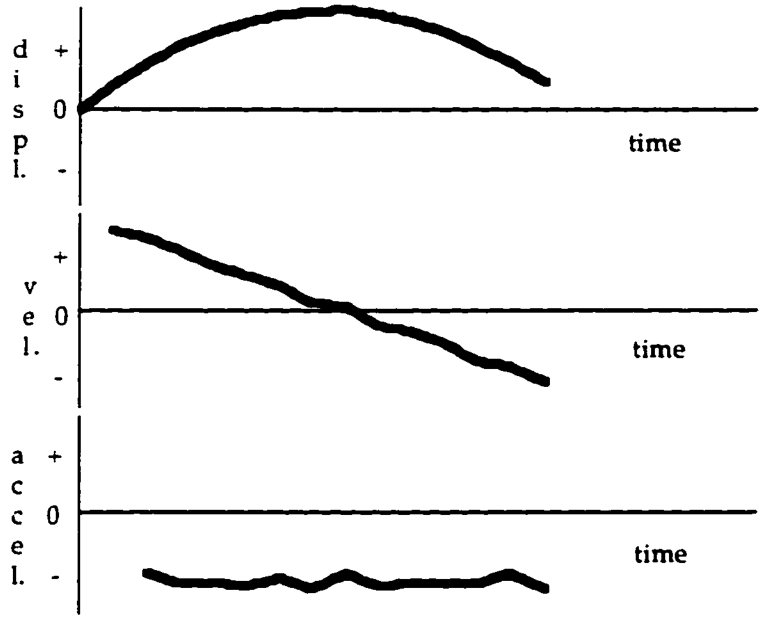

Figure 1. Sample of kinematics graphs of the motion of a basketball (vertical component).

Students learned how to operate the videodisc player through on-screen instructions. Then, they viewed a video segment of the motion to be studied; for example, a basketball free throw. Introductory questions both from the videodisc and from the computer screen helped focus the students on what was to be analyzed. Students chose a spreadsheet screen when they were ready to record data. Students chose a particular recording for the motion to be studied. For example, there were seven recordings of free throws in the basketball sequence from which to choose. Students placed an acetate sheet on the video screen, marked the location of the basketball on the acetate, moved the videodisc two frames forward, marked the location of the ball, and repeated until the basketball's horizontal versus vertical path was recorded (each frame was not marked in order to keep the data of manageable quantity). Students scaled the data by placing the acetate sheet on graph paper, and entered the data into the spreadsheet on the computer. The computer calculated the velocity and acceleration data. The interactive videodisc system then displayed the graphs of displacement versus time, velocity versus time, and acceleration versus time (Figure 1). The real-time group saw each graph drawn simultaneously with the movement of the ball on the videoscreen, and the delay-time group saw each graph drawn several minutes after they saw the video sequence. The graphs in each treatment group were drawn at the same rate. All other aspects of the courseware were held constant.

After the first treatment, the software was modified slightly to improve navigation, and to improve the help screens. No changes in functionality were made.

Design and treatment

A posttest-only contrast-group design was used. Students were randomly assigned to two groups. The experimental group was instructed with interactive videodisc laboratories displaying real-time graphing, and the contrast group was instructed with interactive videodisc laboratories displaying delay-time graphing.

A naturalistic classroom setting was used. The high school had two sections of physics scheduled per day. Fourteen students were in fourth period physics, and seventeen students were in sixth period physics. Two videodisc systems were located in a semi-private area in the back of the physics classroom. During the regularly scheduled physics class, two pairs of students went to the back of the classroom to receive treatments. While treatments were being conducted, the other physics students continued with their regular physics class of discussion, recitation, or laboratory. The instructor for both sections, this researcher, occasionally provided guidance to the research students. After the treatment was completed, the researcher interviewed the subjects. All treatments and interviews were videotaped.

Each of the two sections of physics taught each day had both real-time students and delay-time students to assure uniformity of instruction. The treatments consisted of four laboratory exercises given over a three-week period. The kinematics content areas contained in the treatments were introduced in the regular physics class prior to treatments, so that students knew the terminology and general principles before each treatment. Pairs of students performed the interactive videodisc treatments, with each laboratory exercise lasting about thirty minutes. Qualitative interviews of about five minutes each were given by this researcher after each treatment. After all treatments were completed, each treatment group reviewed each of the four scenes and their corresponding graphs in whole-class instruction. A posttest evaluating graphical skills of kinematics situations was then given to both treatment groups.

Qualitative retention interviews of about 20 minutes each were given by this researcher to eight students three weeks after the last treatment. Two students from each treatment group were selected based on their high score or low score posttest performance and four students were selected randomly, with some selections altered to guarantee that the eight students consisted of four students from each treatment group, four males and four females, and four students from each section of physics.

Instrumentation

The level of achievement in kinematics graphing was determined with the "Questions on Linear Motion" section of the posttest for "Tools for Scientific Thinking" (Center for Science and Mathematics Teaching, 1988). This test determines the understanding of graphing conventions and of the relationships exhibited by graphs in kinematics. Thornton and Sokoloff (1990) have used this test extensively to investigate student learning of kinematic graphing.

Qualitative data were obtained with videotape recordings of students. The treatments, post-treatment interviews, and retention interviews were all videotaped. The researcher used an interview format to elicit information about the students' conceptual understanding of graphical skills. These interviews provided insight into the conceptions the students held about kinematics graphical analysis.

Data collection and analysis

Graphing achievement scores were tabulated, with the students identified by code. The code key was kept separate from the data to assure confidentiality during the analysis. The mean and standard deviation was obtained for the posttest scores and sub-scores. Histograms were produced to determine the distribution of scores.

Posttest achievement scores were analyzed with a one-way analysis of variance. This test determined if the two types of interactive videodisc instruction produced significant differences in mean scores of achievement in kinematics graphing skills. The groups were compared with a level of significance of 0.05. The data were statistically analyzed using both the individual and the laboratory group (since the students worked in pairs) as the units of analysis. Analysis of variance statistics were also completed on subsections of the posttest. A one-tailed analysis of variance was used to determine any differences between males and females in posttest scores. A two-factor (treatment group X gender) analysis of variance was used on the posttest to determine any interaction between treatment group and gender in posttest score.

Transcripts of the students' discussions during treatments, the post-treatment interviews, and the retention interviews were made. Data were processed by the system of unitizing and categorizing as introduced by Glaser and Strauss (1967) and operationally refined by Lincoln and Guba (1985). Unitizing is the process of observing a small "piece of information ... that can stand by itself" (Lincoln & Guba, 1985,

p. 345). For example, a student stating that "negative velocity means slowing down," is a unit. After all units were determined, the different types of units were categorized. For example, the example above was categorized as "difficulty with the concept of velocity." Note that pre-existing categories were not used, but rather the categories emerged from the data. Thus, a pre-existing categorization scheme is not forced onto the data. In this way, the richness of the qualitative data can be fully utilized. Triangulation (using several methods to study the same concept, in order to increase confidence in the validity of qualitative results) was achieved by comparing an individual student's treatment videotape, interview videotape, and posttest, and for selected students, the retention interview.

Chapter IV—Results and Discussion

Descriptive statistics of the population

Since students were randomly assigned to groups, no differences in general ability were expected between groups. Student scores from the Scholastic Aptitude Test (SAT) and/or the American College Test (ACT) Assessment confirmed this prediction. Table 1 and Table 2 show results from an analysis of variance that demonstrates no significant differences between treatment groups. Most students took both the ACT and SAT, but six did not take the SAT, and three did not take the ACT.

Table 1. Analysis of variance of SAT scores of students in each treatment group.

	---------- Mean ---------- (SD)			
Test	real-time N=10	delay-time N=14	$F(1,22)$	p
SAT	1070 (120)	1120 (210)	0.46	0.504
SAT Math	560 (50)	570 (100)	0.04	0.848
SAT Verbal	500 (100)	550 (120)	0.91	0.350

Table 2. Analysis of variance of ACT scores of students in each treatment group.

	Mean (SD)			
Test	real-time N=13	delay-time N=14	$F(1,25)$	p
ACT Composite	25.4 (3.5)	26.0 (4.5)	0.16	0.695
ACT Science Reasoning	24.3 (4.0)	25.6 (5.3)	0.42	0.521
ACT Math	25.1 (2.9)	24.9 (4.5)	0.01	0.921

Posttest performance

Overall posttest analysis.

The real-time group scored higher on the posttest than the delay-time group, but not significantly higher. Table 3 shows posttest scores, the overall score and subscores of questions categorized as displacement questions, velocity questions, acceleration questions, and questions that referred to knowledge of two or three of these areas. Means and standard deviations are shown in Table 4.

Table 3. Posttest scores.

---- Student Information ----			------------------ Posttest Scores ------------------				
Treatment Group	Student Group	Student Number	Total (56)	Displ. Quests. (7)	Vel. Quests. (15)	Accel. Quests. (23)	Mixed Quests. (11)
real-time	3	4	25	3	7	7	8
N=14	3	5	34	1	13	13	7
	5	8	26	2	9	9	6
	5	11	33	4	13	7	9
	7	13	36	4	13	9	10
	8	15	27	2	8	12	5
	8	16	44	6	12	16	10
	10	18	25	4	6	10	5
	10	22	21	1	6	4	10
	11	19	25	2	9	7	7
	11	20	25	2	10	9	4
	15	27	28	2	6	10	10
	15	28	35	2	10	12	11
	16	31	33	7	10	10	6
delay-time	1	1	20	1	5	8	6
N=16	1	2	25	3	6	14	2
	2	3	48	7	14	17	10
	2	7	27	4	8	10	5
	4	6	34	2	11	10	11
	4	10	21	0	8	9	4
	6	9	12	1	5	3	3
	6	14	44	6	12	17	9
	9	17	25	3	7	7	8
	9	23	26	0	9	12	5
	12	21	28	2	11	7	8
	12	24	34	3	11	10	10
	13	25	20	3	8	5	4
	13	29	25	2	6	11	6
	14	26	32	2	9	10	11
	14	30	15	1	6	5	3

Table 4. Posttest mean scores.

Treatment	N	Mean	SD	Std. Error
real-time	14	29.8	6.2	1.7
delay-time	16	27.3	9.6	2.4

An analysis of variance demonstrated no significant differences between treatment groups ($F(1,28)=0.72$, $p<0.404$), as shown in Table 5. The assumptions of parametric tests (random selection, normal distribution, and homogeneity of variance) were met in all statistical tests in this research.

Table 5. Analysis of variance for posttest scores.

Source	df	SS	MS	F	p
Between Groups	1	48.01	48.01	0.72	0.404
Within Groups	28	1869.36	66.76		
Total	29	1917.37			

Histograms of the total posttest scores for the real-time group and the delay-time group appear in Figures 2 and 3. The real-time group showed scores that were more clustered about the mean, and the delay-time group showed scores that were more evenly distributed.

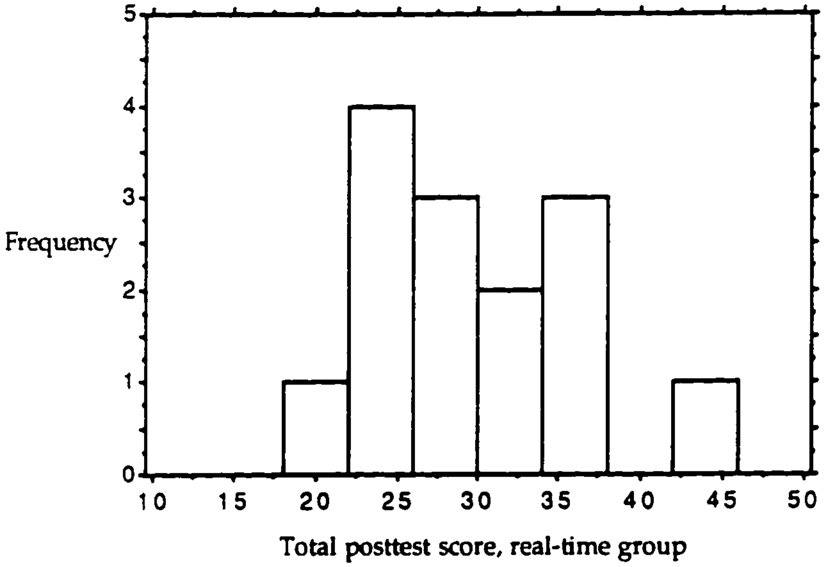

Figure 2. Frequency distribution of total posttest score for the real-time group.

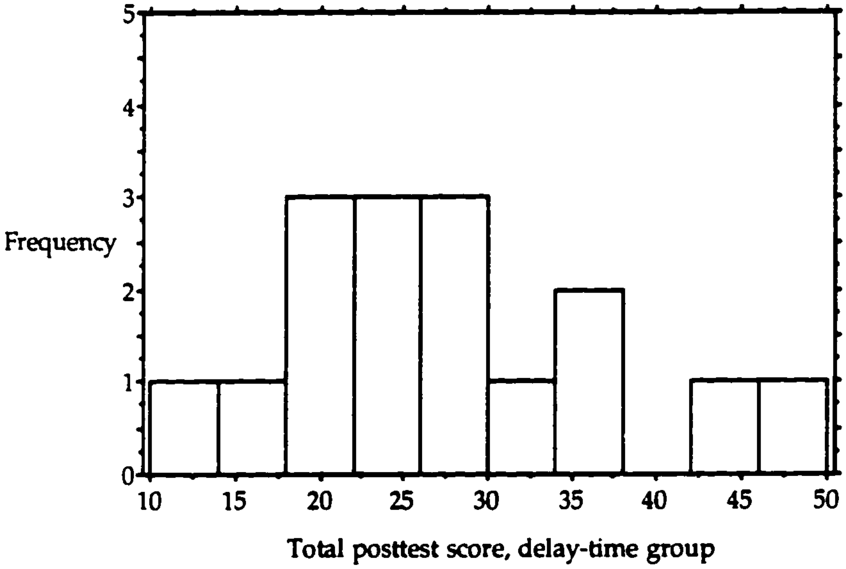

Figure 3. Frequency distribution of total posttest score for the delay-time group.

Topically split posttest questions (displacement questions only, velocity questions only, acceleration questions only, mixed questions only) showed no significant differences. Means and statistical results are shown in Tables 6 through 13. Real-time students scored slightly higher on the displacement questions, velocity questions, and mixed questions. Both groups scored virtually the same on the acceleration questions.

Table 6. Posttest mean scores for displacement subscore.

Group	N	Mean	SD	Std. Error
real-time	14	3	1.8	0.48
delay-time	16	2.5	1.9	0.48

Table 7. Analysis of variance for displacement subscore.

Source	df	SS	MS	F	p
Between Groups	1	1.87	1.87	0.53	0.471
Within Groups	28	98.00	3.50		
Total	29	99.87			

Table 8. Posttest mean scores for velocity subscore.

Group	N	Mean	SD	Std. Error
real-time	14	9.4	2.6	0.70
delay-time	16	8.5	2.7	0.67

Table 9. Analysis of variance for velocity subscore.

Source	df	SS	MS	F	p
Between Groups	1	6.44	6.44	0.91	0.348
Within Groups	28	197.43	7.05		
Total	29	203.87			

Table 10. Posttest mean scores for acceleration subscore.

Group	N	Mean	SD	Std. Error
real-time	14	9.6	3.0	0.80
delay-time	16	9.7	4.0	1.0

Table 11. Analysis of variance for acceleration subscore.

Source	df	SS	MS	F	p
Between Groups	1	0.02	0.02	0.00	0.973
Within Groups	28	356.65	12.74		
Total	29	356.67			

Table 12. Posttest mean scores for mixed questions subscore.

Group	N	Mean	SD	Std. Error
real-time	14	7.7	2.3	0.62
delay-time	16	6.6	3.0	0.76

Table 13. Analysis of variance for mixed questions subscore.

Source	df	SS	MS	F	p
Between Groups	1	9.91	9.91	1.34	0.257
Within Groups	28	206.80	7.49		
Total	29	216.71			

Gender differences.

Brasell (1987b) found some gender differences in the real-time effect, with MBL females scoring significantly higher on distance items, and MBL males scoring significantly higher on the velocity items. Beichner (1990) found no gender differences due to real-time analysis. No gender differences were found in this study. Mean scores by gender are found in Table 14. An analysis of variance showed no significant differences between males and females in posttest scores (F(1,28)=1.99, p<0.169), as seen in Table 15.

Table 14. Posttest mean scores, by gender.

Group	N	Mean	SD	Std. Error
male	17	30.2	9.5	2.3
female	13	26.1	5.3	1.5

Table 15. Analysis of variance for posttest scores, by gender.

Source	df	SS	MS	F	p
Between Groups	1	127.39	127.39	1.99	0.169
Within Groups	28	1789.98	63.93		
Total	29	1917.37			

A two-factor analysis of variance (treatment X gender) demonstrated no significant differences in posttest score by treatment group or by gender, nor any interaction effect (Table 16). An incident table is found in Table 17.

Table 16. Two-factor analysis of variance of posttest scores, by treatment group and gender.

Source	df	SS	MS	F	p
Treatment (A)	1	39.88	39.88	0.60	0.446
Gender (B)	1	130.63	130.63	1.96	0.173
A x B	1	11.22	11.22	0.17	0.685
Error	26	1732.15	66.62		

Table 17. Treatment versus gender incidence table of posttest scores.

	male	female	totals
real-time	8	6	14
	32.1	26.7	29.8
delay-time	9	7	16
	28.6	25.6	27.3
totals	17	13	30
	30.2	26.1	28.4

Student partners as the unit of analysis.

Since the students worked in laboratory groups of two, posttest scores were also analyzed using student partners as the unit of analysis. The scores of each student in a laboratory group were totalled. Means are shown in Table 18. An analysis of variance showed no significant differences between treatment groups ($F(1,13)=0.88$, $p<0.365$), as shown in Table 19.

Table 18. Posttest mean scores, student partners as unit of analysis (posttest scores totalled).

Group	N	Mean	SD	Std. Error
real-time	7	59.1	8.7	3.3
delay-time	8	54.5	10.2	3.6

Table 19. Analysis of variance for posttest scores, student partners as unit of analysis (posttest scores totalled).

Source	df	SS	MS	*F*	*p*
Between Groups	1	80.48	80.48	0.88	0.365
Within Groups	13	1186.86	91.30		
Total	14	1267.34			

Item analysis.

An item analysis of one of the posttest questions showed some differences between the real-time group and the delay-time group. The last question asked the students to sketch the three kinematics graphs for the time interval of zero to six seconds of a ball thrown upward, if the ball reached its peak in three seconds. Thus, a student was given a physical situation, and was asked to draw a graph of the motion. No significant differences were found between treatment groups on the displacement versus time graph or the velocity versus time graph.

However, there was a slight difference between treatment groups on the acceleration versus time graph.

About two-thirds of both groups drew the correct displacement versus time graph. The incorrect graphs were due predominantly to the shape of the graphs, with linear or inverse graphs drawn in place of the parabolic relationship (Figures 4 and 5; note: all student graphs are images directly scanned from the student's paper). Two students drew a distance versus time graph (total distance travelled as continually increasing), ignoring the vector implications of a change in direction (Figures 6 and 7). No significant differences between groups were noted on the displacement versus time graph.

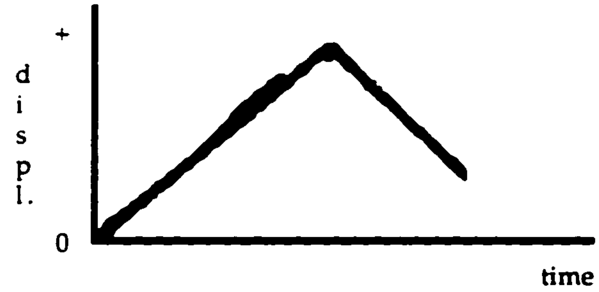

Figure 4. Delay-time student 21 graph of displacement versus time for a ball thrown upward.

Figure 5. Real-time student 4 graph of displacement versus time for a ball thrown upward.

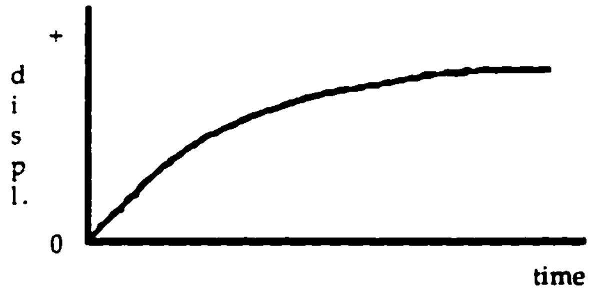

Figure 6. Delay-time student 23 graph of displacement versus time for a ball thrown upward.

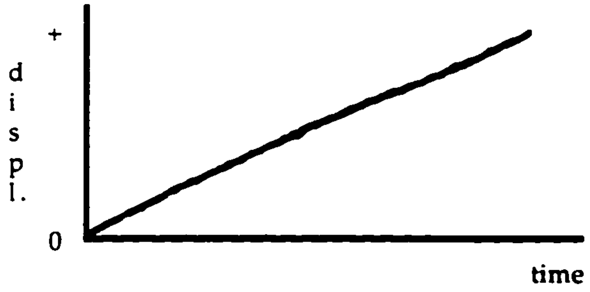

Figure 7. Real-time student 27 graph of displacement versus time for a ball thrown upward.

Both groups have similar results on the velocity versus time graph, with the real-time group doing better (6 of 14, 43% correct) than the delay-time group (4 of 16, 25% correct). Most errors were due to drawing the velocity versus time graph similar to the displacement versus time graph (see Figures 8 and 9). This result is similar to the findings of Peter (1982), Rosenquist and McDermott (1987), and McDermott et al. (1987) in kinematics graphing, and of the description of Trowbridge and McDermott (1980) regarding student confusion of position and speed. McDermott et al. found that when one graph was constructed from another (referring to a velocity graph constructed from a given position graph), "students often seem unable to ignore the shape of the original graph" (1987, p. 505).

The rest of the errors in the velocity versus time graphs were problems in sign, in shape, in starting point, or with graphs containing discontinuities. For example, some students demonstrated the difficulty with negative velocity that Goldberg and Anderson (1989) discussed. Student 25 used a discontinuity at t=3 seconds to avoid negative velocity, have velocity changing, and still show that the velocity was zero at the top of the ball's path (Figure 10). This student also insisted that velocity began at zero, which could mean the student was thinking the graph was measured from the beginning of the throw, not from the point of release (see further discussion of this point under theme seven below). Student 22 accepted the concept of negative velocity, yet thought that the velocity was constant and positive on the upward flight, constant and negative on the downward flight, and also had a discontinuity at t=3 seconds (Figure 11).

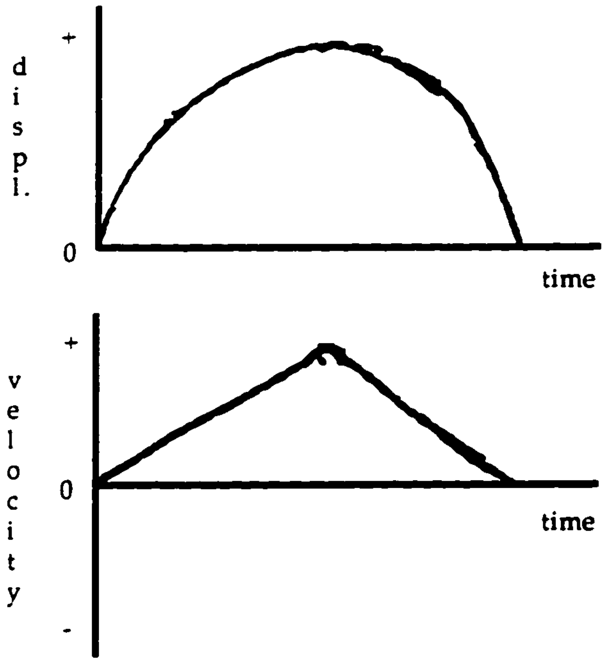

Figure 8. Delay-time student 26 graphs of displacement versus time and velocity versus time for a ball thrown upward.

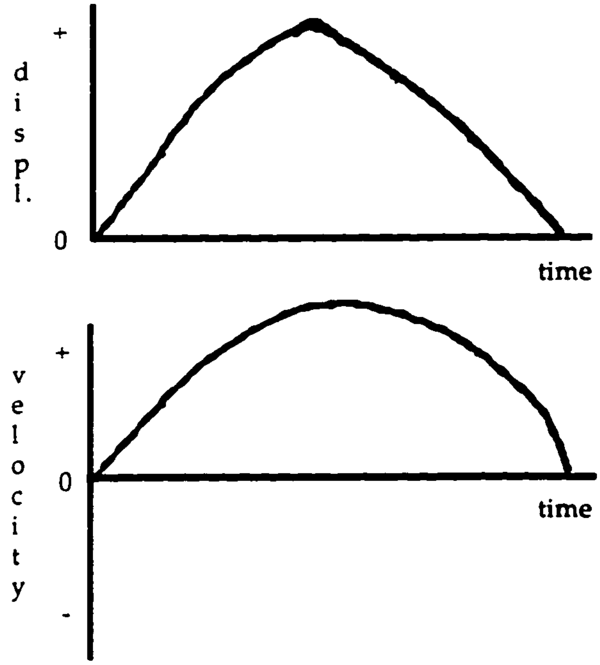

Figure 9. Real-time student 15 graphs of displacement versus time and velocity versus time for a ball thrown upward.

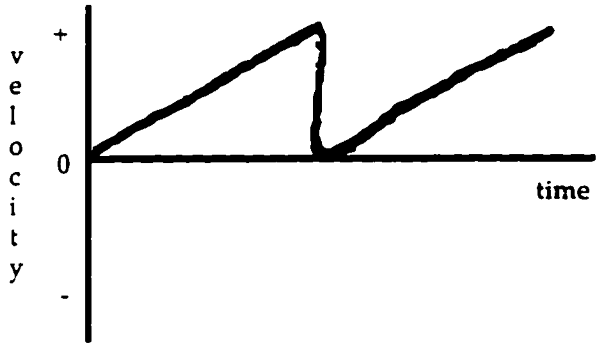

Figure 10. Delay-time student 25 graph of velocity versus time for a ball thrown upward.

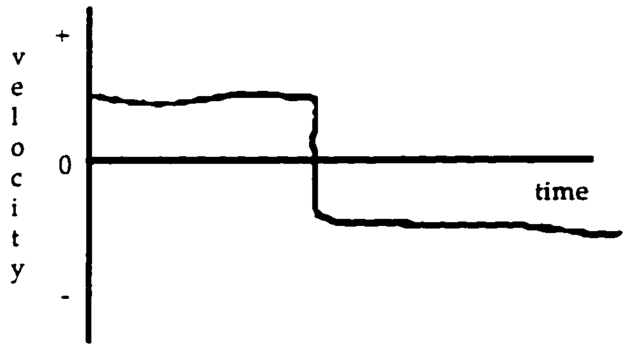

Figure 11. Real-time student 22 graph of velocity versus time for a ball thrown upward.

The acceleration versus time graphs for the ball thrown upward demonstrated a slight difference between treatment groups. The number correct was similar, with the real-time group performing slightly better (8 of 14, 57%) than the delay-time group (6 of 16, 36%). However, the real-time group only had one instance of the acceleration versus time graph being similar to the velocity versus time graph (1 of 14, 7%) whereas the delay-time group had five instances of this confusion (5 of 16, 31%). Example graphs are shown in Figures 12 and 13.

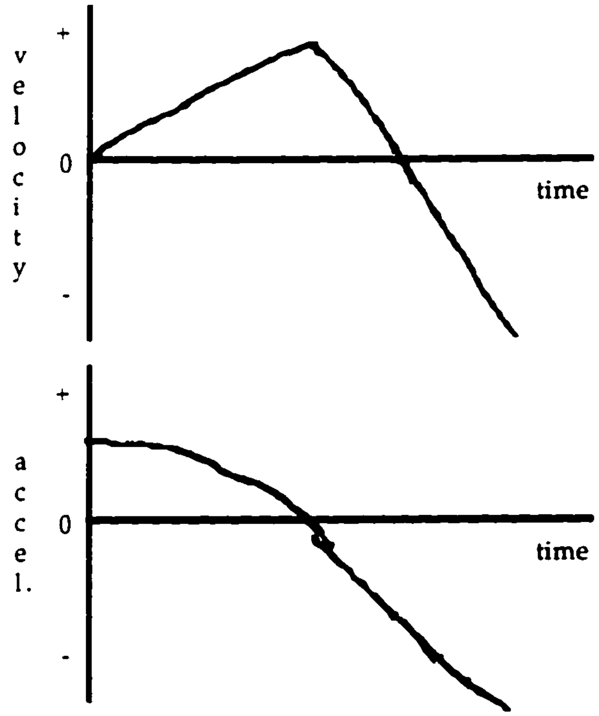

Figure 12. Real-time student 19 graphs of velocity versus time and acceleration versus time for a ball thrown upward.

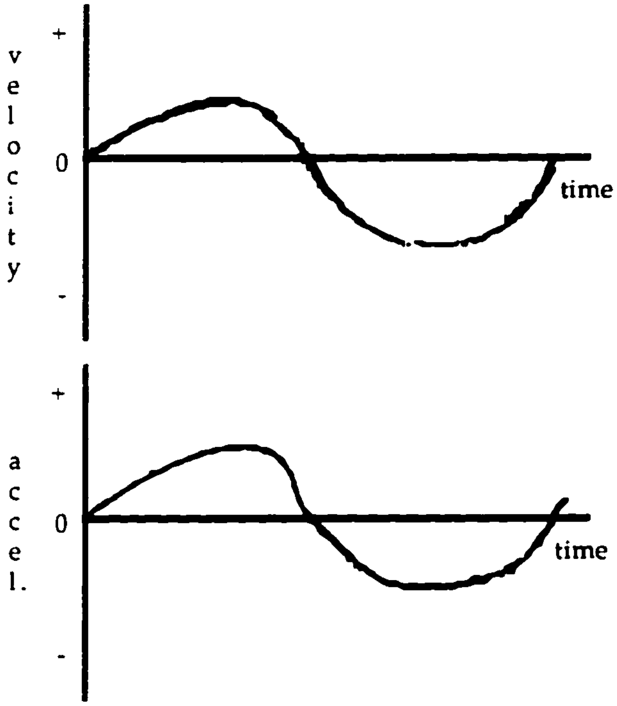

Figure 13. Delay-time student 7 graphs of velocity versus time and acceleration versus time for a ball thrown upward.

The confusion of acceleration and velocity is described by Trowbridge and McDermott (1981) and the confusion of kinematics graphs of acceleration and velocity is described by McDermott et al. (1987). Trowbridge and McDermott (1981), in an example of a ball rolling upwards and downwards on an incline, found that students "expressed the belief that when the direction of motion of the ball changed, the direction of the acceleration changed, and therefore had to pass through zero" (p. 248). Thus, an acceleration graph that is shaped like a velocity graph appears reasonable to students.

Why did real-time students do better in this aspect of kinematics graphing? Perhaps the "chain of cognitive accomplishments" that

Linn et al. (1987) posited for graphing is augmented by the real-time effect, especially for higher-level abstractions. The item analysis of the posttest showed that the delay-time students did not confuse the displacement/velocity graphs, graphs that are more at the concrete level of the conceptual scale, as compared to the velocity/acceleration graphs, graphs that are more at the abstract level of the conceptual scale. The real-time students were more successful at this level of abstraction.

Another error on the acceleration graph was a "stair-step graph" where a student thought acceleration was constant and positive on the way upward, constant and negative on the way downward, and zero at the peak; thus, a discontinuity was drawn at t=3 seconds (Figure 14). One of the most interesting acceleration graphs was from Student 28, who drew a similar "stair-step graph," but used step function notation learned in mathematics class to describe the misconception that acceleration was zero at the top of the ball's path (Figure 15). This student tried to tie his mathematics knowledge to his physics graph, yet he did not recognize the physical problems associated with this graphical representation. Yeatts and Hundhausen (1992) described this as "missing the connection, where the calculus concept may be fairly well understood but a change in context or notation confounds the student" (p. 718).

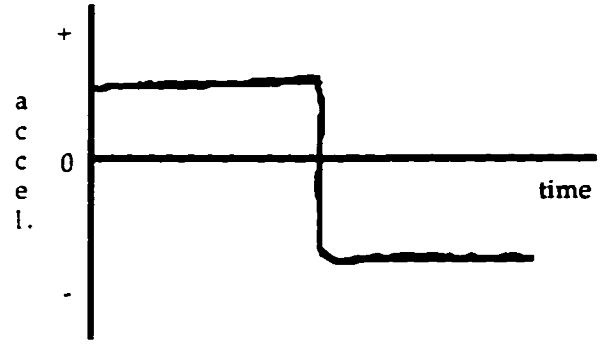

Figure 14. Delay-time student 26 graph of acceleration versus time for a ball thrown upward.

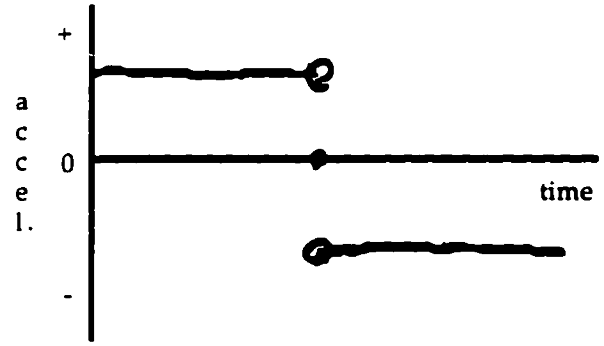

Figure 15. Real-time student 28 graph of acceleration versus time for a ball thrown upward.

Qualitative results

Introduction.

Each of the 16 student groups were videotaped during all treatments, and during the interviews at the conclusion of each of each treatments, for a total of 64 videotaped records. Forty of these videotaped records were transcribed. These transcripts represent 19 students; nine students from five real-time groups (one student was without a partner), and ten students from five delay-time groups. In addition, all eight of the retention interviews were videotaped and transcribed. All transcripts represented the same 19 students. Five complete transcripts are shown in Appendix B.

Several recurring themes emerged from an analysis of the transcripts of the videotapes. Some of the student comments can be described as misconceptions or alternate conceptions of physical phenomenon, some as difficulties with relating a physical event to an abstract graph, and others as an inability to articulate a rigorous explanation of the physics involved. These themes do not always stand alone, but are usually related to other themes. Categorization of student comments as particular themes is subjective. For example, is the student comment a confusion between velocity and acceleration, or is the comment specifically a misunderstanding of acceleration? Comments that could fit into multiple categories were analyzed within the context of the student remarks to determine what the dominant misconceptions seemed to be. Examples from student transcripts follow each theme. Many corroborated the findings of McDermott et al. (1987), but some are new. Interviews were recorded by code:

Last digit:
    1 = real-time, and
    2 = delay-time.
Second-to-last digit:
    1 = first treatment, constant velocity,
    2 = second treatment, 1-D, horizontal, accelerated motion,
    3 = third treatment, 1-D, vertical, accelerated motion,

4 = fourth treatment, projectile motion, and
5 = retention interview, projectile motion.

First one or two digits: student group number.

People involved in transcript:
I = interviewer, and
S24 = student number 24.

Parenthetic material refers to this researcher's comments regarding the transcript.

Ellipses (...) refer to pauses, inaudible responses, or incomprehensible responses by the students.

Braces with a number {3} refer to the number of the theme represented by the comment.

For example, <511> refers to student group 5, treatment 1, and real-time; <1452> refers to student group 14, retention interview, delay-time.

Themes of student comments.

Student comments were unitized, then categorized into ten themes. All themes and their sub-themes are listed here, and then each theme is described in its own section. The frequency of themes from each treatment group is shown in Table 20, using the laboratory group as the unit of analysis. Also included in this table is the number of lines of comments the students made to each other during the graphing portion of the treatment, which is discussed under theme one. The frequency of themes was analyzed with the Mann-Whitney U statistic, which showed no statistically significant differences between treatment groups (Table 20).

Recall that on the posttest, a student was given a physical situation, and was asked to sketch graphs of the motion by hand.

During the treatments, the student was asked to describe and explain the graphs that were drawn by the computer.

Theme one—Real-time versus delay-time differences.

1. Student awareness of the real-time effect, or the real-time effect as a motivating factor.
2. Eye movement—did the real-time students concentrate on the computer screen, the video screen, or move their eyes back and forth between the two screens while the graphs were being drawn?
3. Amount of discussion during graphing.
4. Real-time effect—was it lasting, or was it a novelty the first or second treatment?

Theme two—Graph as a picture error.

Theme three—Use of vocabulary.

1. Misuse or lack of use of the word "constant" when describing a graph
2. Colloquial use of "up" and "down", e.g., "velocity goes down" when they should say increase or decrease.
3. Miscellaneous vocabulary problems.
4. Omission of units.

Theme four—Difficulties with velocity.

1. Magnitude of velocity.
2. Direction of velocity.

Theme five—Difficulties with acceleration.

1. Direction of acceleration.
2. Acceleration compared to deceleration.
3. Discontinuous acceleration.

Theme six—Confusion between different types of graphs or types of physics concepts.

1. Displacement/distance confusion.
2. Displacement/velocity errors.

3. Velocity/acceleration errors.
4. Displacement/acceleration errors.
5. Displacement/velocity/acceleration errors.

Theme seven—Misconceptions about shape or starting point of graph.

1. Fluctuations of graph.
2. Starting point of graph.
3. Sharp changes in graph not physically possible.
4. Students don't give value of graph (+, -, or 0), or mis-read values of graph.
5. Students misstate the shape of graphs.
6. Students more comfortable with spreadsheet numbers than with an abstract graph.

Theme eight—Students wanted to ignore graphical abstracts in favor of giving a physical description, or a memorized definition.

Theme nine—References to dynamics.

1. Force misconceptions.
2. Gravity comments.
3. Is the graph describing the ball while it is still in the hand, or after it had been released?
4. Air resistance comments.

Theme 10—References to slope or calculus.

1. Slope comments.
2. Calculus comments.

Table 20. Frequency table and Mann-Whitney U test of themes, laboratory group as unit of analysis.

Theme	frequency count (mean rank)		Mann-Whitney U test	
	real-time (N=5)	delay-time (N=5)	z	p
1. Real-time versus delay-time differences	14 (6.9)	5 (4.1)	-1.46	0.144
2. Graph as a picture error	9 (5.3)	9 (5.7)	-0.21	0.835
3. Use of vocabulary	19 (6.7)	9 (4.3)	-1.25	0.210
4. Difficulties with velocity	10 (4.7)	13 (6.3)	-0.84	0.403
5. Difficulties with acceleration	15 (5.5)	15 (5.5)	0.00	1.000
6. Confusion between different types of graphs or physics concepts	23 (4.3)	34 (6.7)	-1.25	0.210
7. Misconceptions about shape or starting point of graph	11 (4.8)	17 (6.2)	-0.73	0.465
8. Ignore graphical abstractions and give physical description	2 (*)	2 (*)	*	*
9. References to dynamics	22 (5.1)	26 (5.9)	-0.42	0.676
10. References to slope or calculus	5 (3.9)	17 (7.1)	-1.67	0.095
X. Number of lines of comments	179** (5.5)	106** (3.5)	-1.16**	0.248**

* frequency count too small to use this statistic.

** real-time N=4 and delay-time N=4 due to one missing data set and one student without a partner.

Theme one—Real-time versus delay-time differences.

1. Student awareness of the real-time effect, or the real-time effect as a motivating factor:

Students from the real-time groups commented positively on the real-time effect ten times, whereas the delay-time groups only referred to both screens once. Each group also had four instances which referred to a lack of discussion or a lack of watching both screens during graphing. These data imply that the real-time group was aware of the real-time effect. This may be because it was different from the norm; i.e., it was unusual to have real-time graphing. Clark (1985) referred to this notion as a novelty effect, and he noted that most computer-assisted instruction studies that have a short treatment period may show exaggerated learning gains as compared to longer treatments due to this effect.

At times, instructional methodologies do not improve learning because the students are not aware that a particular technique is being used, or why the technique is being used. For example, some students are frustrated by discovery laboratories, because the students want a "cook-book" approach, yet if the instructor explains why a discovery approach is used, and the students are cognizant of the methodology, they are more comfortable with the approach. The present research showed that the real-time groups did notice the real-time effect, and made use of it. However, such knowledge did not produce significant learning gains as compared to delay-time students. The following interviews show students aware of the real-time approach:

Example <311>, real-time, 1-D constant velocity, runner:
S5 Look at that. Bad! They are doing it as he is running (*{1} noting real-time effect). He's running and accelerating and decelerating. Like every time he jumps off, boom, boom, boom (*good—noting fluctuations in graph caused by human running motion). OK, velocity vs. time.

Later, same interview:
S4,S5 I like the graph. I like the...how they had this moving while they were plotting the graph. Yeah, that was neat.
S4 Well, you can observe, um, with the way he's running how that's all measuring out on the....
S5 Yeah, like if he had a sudden acceleration for some reason, like if he decided to sprint all of a sudden.
S4,S5 You could see how it happened on the screen...you can see the difference in distance...like if he stopped all of a sudden.

This interview also showed that the real-time effect was a motivating factor. The students were very excited about recognizing the graph being simultaneously drawn with the motion. Brasell (1987a) saw a lack of motivation in the "delayed-MBL groups" (delay-time groups), noting that these groups "appeared to be less motivated, less actively engaged, less eager to experiment, and more concerned with procedural than conceptual issues" (pp. 393-394). Such a motivating effect in the real-time students would seem a positive influence on student learning. Other examples of real-time student comments also illustrate these points:

Example <811>, real-time, 1-D constant velocity, runner:
S16 You're kidding, that is so fresh (*{1} looking at real-time effect)! Oh my gosh! That is bad!

Later, same interview:
S16 It was real neat the way it did that (*{1} real-time effect).

Example <321>, real-time, 1-D non-zero acceleration, sprinter:

S5 It should go up in a linear, nifty line (referring to d vs. t). Acceleration versus time. Here we go! Each time he took a step (*{1} pointing to both screens at once).... Whoa! I don't understand that, I think we did something wrong (*{7} fluctuations). Try that again. Step, slows down, takes a step again, slows down, takes a step again, slows down.... We screwed up somewhere.

Later, same interview:
I Tell me about the velocity versus time.
S5 Each time he took a step, he slowed down, you can see that (*{1} points to both screens—this student was strongly affected by the real-time approach, also he is very animated in answering). But it went up too, his velocity increased.
I You mean his overall trend?
S5 Yeah. If you drew the best-fit line, it would kind of go up like this.
S4 Yeah, a slight, gradual increase, but you could tell that every time he took a step....

Later, same interview:
I Does the graph make sense, to what the runner was doing?
S5 Other than the acceleration, with this big down.
S4 As we went along, you could tell when he took a step, where the graph would go (*{1} real-time).

Example <821>, real-time, 1-D non-zero acceleration, sprinter:
S16 On all of him the velocity was the same except for that first little bit. Until it got there, and then it followed it exactly. That's pretty neat.
S15 That's cool (*{1} noting real-time effect).
S16 This should look a lot more (refers to a vs. t).... That's a trip!

Example <1041>, real-time, 2-D freefall, ball:
I OK. How about velocity versus time?
S22 Every second it slows down.
I Alright. Keep going—what happens then?
S22 First, it's above zero (referring to graph), and that means it's going up (referring to ball), and when it's below zero, it's going down (*good).
I OK, and what about zero (leading question?)?
S22 Zero is probably when it's right there (*{1} points to video monitor, and both Mac graphs).

There was one instance where a delay-time group referred to both screens at once. The following student showed a cognitive link between the motion and the graph, even though the two situations were not simultaneous. This demonstrated an instance where a delay-time student made the appropriate link without the real-time technique:

Example <242>, delay-time, 2-D freefall, ball:
I Alright, what about velocity versus time?
S7 The velocity is positive, positive, positive, then it hits its peak (she is mimicking her partner's previous explanation—does she really know?) and it goes negative.
I What does that mean? What does positive mean?
S7 Positive velocity means it's moving, its moving up, and negative means it's moving down (she does seem to understand).
I OK, what can you say about the peak?
S7 It hits its peak right here in the graph (points to computer screen) and right here (points to video screen—*{1} even though delay-time, she refers to both screens for one instant of motion; interesting).

2. Eye movement—did the real-time students concentrate on the computer screen, the video screen, or move their eyes back and forth between the two screens while the graphs were being drawn?:

Data are sketchy, since only eight complete observations of actual eye movements were made, from four different student groups. In many of the treatments, eye movement data could not be observed due to the camera angle, one student blocking another, or a student having his/her head turned. In other treatments, the students only looked at the graph on the computer screen. Data showed that students reduced the number of eye movements between screens throughout the graphing portion of a treatment (Table 21).

Students averaged nine eye movements on displacement versus time, five eye movements on velocity versus time, and three eye movements during acceleration versus time. A Friedman test showed there was a significant effect on the frequency of eye movement from video monitor to computer screen for the series of three graphs, $\underline{p}<.05$ (Table 22). The Nemenyi post-hoc procedure showed a significant difference between the frequency of eye movement during the displacement graph and during the acceleration graph. These data imply that students are more likely to keep a mental picture of the event during subsequent graphs after they have seen one graph produced. Students typically watched the three graphs one after another, so the event was fresh in their minds. Thus, the "memory support" (Linn et al., 1987, p. 252) of the real-time environment seems not as important when viewing several graphs one after another.

Table 21. Frequency of eye movement between screens during graphing, real-time groups.

Graph	N	Mean	SD	Std. Error
displacement vs. time	8	8.8	3.0	1.1
velocity vs. time	8	5.4	4.1	1.5
acceleration vs. time	8	3.1	1.8	0.6

Table 22. Friedman test for repeated measures of frequency of eye movement between screens during graphing, real-time groups.

Graph	mean rank (N=8)	df	χ^2	p
displacement vs. time	2.69	2	9.188	0.010*
velocity vs. time	2.13			
acceleration vs. time	1.19			

* significant at the 95% level

However, delay-time students also have to keep a mental picture of the video event, since their graphs were all drawn several minutes after the event was shown. These delay-time students performed similarly on the posttest; thus, it seems that during an extended treatment, real-time students make less use of the real-time effect, and delay-time students do not have a disadvantage due to not having a real-time effect.

The two-screen system could be a distraction. Other computer systems, such as QuickTime on the Macintosh or Video for Windows on the IBM would eliminate the problems inherent in a two-screen system by providing the graph and the video on the same screen. This puts the video of the event and the graph in closer proximity. However, a MBL does have the graph production and the actual laboratory event in two locations, and the students must attempt to attend to both events. Thus, in any real-time environment involving a laboratory experiment, students must watch an event and a computer screen simultaneously.

3. Amount of discussion during graphing:

Some differences (not statistically significant) were found between groups in the amount of discussion among partners while the graphing was accomplished. The delay-time groups averaged 25 lines of comments during the graphing portion of the treatments (about six lines per treatment), and the real-time groups averaged 45 lines of comments (about 11 lines per treatment). Thus, delay-time groups had about 45% fewer comments during graphing than the real-time students. The real-time students seemed to be more animated and descriptive. Does this mean the real-time has a motivating effect? If so, it would seem to be an advantage.

4. Real-time effect—was it lasting, or was it just a novelty for the first or second treatment?:

Transcripts revealed that students referred less to the real-time effect as the treatments continued. The first and second treatments produced four positive comments each regarding the real-time effect; the third and fourth treatments produced one positive comment each. This result suggests that the effect of the real-time treatment decreased as students became accustomed to it, which could imply a novelty effect.

Theme two—Graph as a picture error.

Y versus x description of graph instead of y versus t error:

This error is a well-documented misconception (see Leinhardt et al., 1990, pp. 39-42 for a review of this misconception). Students often view graphs as pictures, not as functional relationships. They believe an y versus x graph (vertical position versus horizontal position graph) of an object (for example, as marked on the acetate) is identical to the displacement versus time kinematics graph. For example, when asked for a position versus time graph of a ball rolling up and down a series of hills, the student draws the shape of the hills. Real-time and delay-time students had the same frequency of difficulty with this concept. McDermott et al. (1987) called this "separating the shape of a graph from the path of the motion" and they said students are attempting to "reproduce the spatial appearance of the motion" (p. 509). Several examples of student "picture" errors follow:

Example <442>, delay-time, 2-D freefall, ball:
I Tell me about the basketball, displacement vs. time.
S10 This is when he shot it, and that's when it hit the hoop (points to graph).
S6 It looks like this (holds acetate up) (*{2} y vs. x picture error).
S10 It had to get a curve going so it could get the distance, and it fell.
I So, those two graphs are the same?
S10 Uh, huh.
S6 More or less, ...that's not the whole, that's not there (referring to the end of the graph).

Example <841>, real-time, 2-D freefall, ball:
S16 This (d vs. t) should go...(draws concave downward curve on the screen with his finger).
S15 It just goes the same as this (holds up acetate—*{2} y vs. x picture error).

Later, same interview:
I What do you think about displacement vs. time?
S16 The coolest thing I found about it was that, even though this was measuring only horizontal velocity, it's pretty much a perfect copy of our graph. The graph we were only measuring vertical distance, and this (graph) was only measuring vertical distance, but both of them were in the same time frame as the horizontal

> distance too. They were both in the same time frame, and so this (graph) is pretty much an exact copy of that (acetate). As far as displacement is concerned, this is pretty much the flight path of the ball; the ball is peaking right here at the peak of the graph and has started to come down. The most important thing I got out of it was that it proved they were both in the same...that time was always constant, as it is in the equations (*{2} still y vs. x picture error).

No significant differences were found between treatment groups with regard to the graph as a picture error.

Theme three—Use of vocabulary.

Some of the comments students made during interviews are vocabulary-related items. Students are not fluent with the vocabulary of physics, so they often use everyday life descriptions that are not very physically accurate. One important aspect of physics is to communicate physical relationships and ideas to others; thus, if vocabulary is improperly used, confusion can result in scientific communication. Some errors due to vocabulary are discussed in this theme, and other errors are discussed within other themes. For example, the student statement "the acceleration should be descending" is discussed in theme five, difficulties with acceleration.

Some vocabulary errors could have occurred when the student misspoke, as we all do. Other errors occurred since students use the language of physics in a different way than physicists use the language of physics. Touger (1991) described this use of language:

> What is less evident is that the body of Newtonian mechanics currently taught to students and the language in which it gets

> imbedded, which we tend to regard as existing in a coherent and self-consistent steady state, may only exist in such a state for the experienced physicist or physics teacher who has developed and internalized sophisticated skills of filtration and interpretation. How the concepts and language appear to our students may be quite another matter (p. 90).

One such vocabulary error was missing units, which was made ten times by the real-time group and three times by the delay-time group (this is discussed below). Other errors of the use of the vocabulary of physics were made nine times by the real-time group, and six times by the delay-time group. Errors include:

1. Misuse or lack of use of the word "constant" when describing a graph:

Students used the words "equal" or "same" when they should use the word "constant" when describing a graph. This is similar to Arons' (1990) description of the use of "uniform" in the context of uniform motion, where "texts and teachers frequently overlook the fact that many students do not really know what the word 'uniform' means" (p. 24). In the context of velocity, the students should use "constant" or "uniform" with a "description such as 'equal change in position in each succeeding second'" (Arons, 1990, p. 24). Brasell (1987b) notes that "'steady' velocity is less precise than 'constant' velocity" and that this type of "non-scientific description is considerably more ambiguous" (p. 67). The students misused the word "constant" in the examples below:

Example <511>, real-time, 1-D constant velocity, runner:
I Tell me about the displacement.
S8 He travelled...his distance constantly got...increased as his time increased. And, since he should have been running at a constant pace, the velocity should have been just a straight line.
I Why is that?
S8 Cuz, for every yard he ran, ...
S11 If his distance is increasing at the same rate (*{3} vocab.—"constant rate") as his time, then velocity should be equal (*{3} vocab.—"constant vel").

This student seems to know the concept that displacement is increasing linearly with time, yet the idea is not communicated accurately. "The same rate" is not clear, since it does not tell what the rate is (same as what rate?). Similarly, "the velocity should be equal" to what velocity? This analysis might be overly critical, yet accurate communication of ideas, both oral and written, is essential in physics.

Example <1021>, real-time, 1-D non-zero acceleration, sprinter:
I What'd you get for displacement?
S22 It's pretty constant (*{3} vocab.—wrong meaning of constant).
I Displacement is constant?... What is the shape of the graph?
S22 It's an upward slant, but it's a constant, it's constantly going up (*{3}—vocab.) at the same...I mean it's not, like, connected or anything....

Here "constant" was used for "linearly increasing" or for "constant slope." The student elaborates somewhat with "constantly going up," yet even that should be "linearly increasing," or "constant slope." Similarly, another student used this vocabulary error:

Example <851>, real-time, retention interview, 2-D freefall, ball:
S16 Velocity: I drew this on the assumption, I did not include the throw in this. If I were to include the throw, your velocity would increase dramatically, then decrease at a steady rate. Because the acceleration is constantly -9.8 (*{3} no units), due to the effects of gravity. So, after the throw, you start with a positive velocity, and you have a constant decreasing velocity (*{3} constant decrease?, does he mean linearly decreasing?), due

> to gravity, and at this zero point right here, three seconds after the throw, you're at the peak, the ball is still, it has no, zero velocity, then, steadily at the same rate, increases in the negative direction, coming downward.

This student could be confusing velocity and acceleration, since his "constant decreasing velocity" could refer to a constant acceleration, with decreasing magnitude of velocity. He recovers somewhat in the end, with a fair description of velocity, yet still does not explicitly state if his reference is to acceleration or velocity.

2. Colloquial use of "up" and "down," e.g., "velocity goes down" when they should say increase or decrease:

The terms "up" and "down" were commonly used by students (and instructors) to mean increase or decrease. Arons (1990) used the locutions of "up" and "down" to mean a change in magnitude, both in the context of scaling (p. 11), and in the context of magnitude of velocity (p. 29). Similarly Peters (1982) used "speeding up and slowing down" to describe a changing magnitude of velocity (p. 502). For example:

Example <521>, real-time, 1-D non-zero acceleration, sprinter:

I So there is no difference between the runner and the sprinter (*software: should have a way to quickly recall that computer data, so the student could compare.)?

S8 Right. It's the velocity that's different.

S11 The sprinter is going to go faster than the distance runner does in the same length of time.

S8 But that doesn't have anything to do with that (points to d vs. t).

S11 I think it would speed up (*{3} vocab.—instead of "increase his velocity"), his distance..., until he reached his maximum speed, his displacement would continue to grow, then flatten out in a straight line, as he increases his speed.

S8 This doesn't have anything to do with speed, just distance and the amount of time it took him to go that distance. So, they should be the same (still problem).

Example <212>, delay-time, 1-D constant velocity, runner:
I That might help. What's happening on the velocity?
S7 His velocity went up (*{6} confusion between types of graphs error, *{3} vocab.—"went up" instead of "increased"), really sharp.
S3 It should remain the same.
I What do you mean, remain the same, the velocity?
S3 Should remain constant.
I What do you mean, constant?
S3 Same, same horizontal line.
S7 Same velocity (*good).

In these examples, students seemed to use the word "up" for "increase" in a logical and consistent manner in reference to the magnitude of velocity. Similarly, students use "down" in reference to the magnitude of acceleration (although they are confusing acceleration with velocity; see theme six below):

Example <341>, real-time, 2-D freefall, ball:
I What about acceleration?
S5 It continually slowed down a little bit (talking about vel.?). To zero.
I That last part might be an error. What about the first part?
S5 It just was basically slowing down a little bit (*{3} vocab. error—he's talking about vel.), but had no acceleration, ...in the positive sense.

Later, same interview:
S4 The average of the acceleration was more of a slow down than a speed up (*{3} vocab.).

Example <1242>, delay-time, 2-D freefall, ball:
I Going up, what's happening to the velocity?
S24 It goes up for a tiny bit when he throws it. This point right here is when it reaches the peak of its arc, when it has zero velocity.
I OK, before that, what happens to the velocity?
S24 The velocity is going down (*{3} vocab., should say "decreasing"), because when it rises up, it's still being pulled on by gravity (*{9} dynamics).

These first two examples imply that "down" means "decreasing," yet the last example could lead to confusion between the magnitude of the velocity and the direction of the velocity. Note how "up" is used as a direction right after "down" is used as a magnitude. Thus, students may be confused regarding the use of up/down, or they may at the least be unclear in their descriptions. Arons (1990) similarly uses "up" and "down" (p. 31), or at times "upward" and "downward" for direction (p. 96). This researcher consistently used "upward" and "downward" to refer to directions during instruction. However, the students rarely use the terms "upward" and "downward" when they described direction in their interviews.

Should up/down be used as a magnitude, a direction, both, or neither? One alternative is to use upward/downward for direction, increase/decrease for magnitude, and avoid up/down altogether. This would avoid ambiguity, and make communication clearer. However, an attempt to do this in this researcher's instruction proved difficult, since up/down for magnitude is so ingrained in everyday vocabulary.

3. Miscellaneous vocabulary problems:

Students used colloquial vocabulary such as "speed" instead of "rate," or "faster" instead of "greater:"

Example <1422>, delay-time, 1-D non-zero acceleration, sprinter:
I How does that differ than the distance runner last time?
S26 He just stays the same, constant.
I What do you mean, constant?
S26 It increased at the same speed (*{3} vocab.—"speed" instead of "rate"?).

Example <1432>, delay-time, 1-D freefall, cheerleader:

I What if you were going to take an overall acceleration, an average?... Positive, negative, zero (leading question)?
S26,S30 Negative.
I What does that mean?
S26 That she's going faster while she's going down. She accelerates faster as gravity (*{9} gravity) pulls her down (*{5} change in accel., or *{3} vocab.: "faster" instead of greater).

These examples again demonstrate colloquial use of vocabulary, yet both cases show reasonable understanding of the overall concept involved.

4. Omission of units:

As any science teacher knows, students regularly omit units in their oral and written work. This is common in everyday life, "the temperature is 95," and it is reinforced in many math classes, "the area is 15." Student interviews demonstrated numerous examples of the omission of units:

Example <252.8>, delay-time, retention interview, 2-D freefall, ball:
I I don't know. We talked about what value acceleration due to gravity was.
S7 Yeah. Negative and positive 9.8 (*{3} no units) you mean?... The acceleration due to gravity is always just positive 9.8, but the acceleration of something in freefall can be either negative or positive, it just depends on what it is doing (*{5} neg. accel. problem).

In summary, the imprecise or erroneous use of vocabulary by students was consistent between the real-time group and the delay-time group. It is recognized that sometimes it is difficult to know if a misconception has occurred due to use of vocabulary. Trowbridge and McDermott stated that "just as it would be a mistake to assume that all misuse of technical vocabulary reflects lack of understanding, it would be equally erroneous to dismiss without careful probing ambiguous use of technical vocabulary as mere carelessness" (1980, p. 1028). More in-depth interviews would prove useful to probe the misuse of vocabulary to determine the level of misconceptions or of proper concept understanding.

Theme four—Difficulties with velocity.

1. Magnitude of velocity:

The following student thinks the velocity of the cheerleader increases as she is tossed upwards:

Example <632>, delay-time, 1-D freefall, cheerleader:
I How about velocity versus time? Go ahead and hit that button (didn't graph yet).
S14 (predicting) It would increase, then it would peak out, then it would really increase in the negative direction.
I What does that (graph) mean? What's the velocity doing?
S9 It's decreasing all the time (*{4} freefall velocity is "decreasing always" error).
I Decreasing? It starts out, what, positive or negative?
S9 Positive.
I Positive. And then decreases to what? Doesn't it hit the axis? What does that mean (question too leading?)?
S9 Falling down.
I Does that mean velocity is what: positive, negative, or zero?
S9 Negative (*{4} error).
I Isn't that zero velocity?
S9 Yeah (just agrees to what I say; seems to have little understanding).

The student could be thinking about the time from when the cheerleader begins to be pushed. At that time she *is* increasing velocity. If the student means "decreasing always" to mean velocity went from +2 m/s to 0 m/s to -2 m/s, then he was correct. However, students are usually talking about speed, which decreases to zero on the way upward, then increases on the way downward. Physics teachers need to be more careful about this aspect of vector velocity. Dykstra et al. (1992) pointed out that at times, "students find the notions of greater than (>) and less than (<) incongruous. The words 'greater' and 'less' are most closely associated with magnitude so that the idea that -49 > -50 seems inconsistent with this" (p. 637).

The following student says that the velocity is constant when it is actually increasing (also see vocabulary theme three discussion):

Example <222>, delay-time, 1-D non-zero acceleration, sprinter:
I What in general, is happening (v vs. t)?
S3 I think the velocity should be pretty much constant (*{4} vel. error—velocity of sprinter is increasing). It is positive.
S7 So we know he's going forward.
S3 You know he is increasing his slope (*{10} slope) right here.
I What does that mean?
S7 Rise over run.
I What does that result in?
S3 It results in a greater amount of distance covered in the same period of time (*good).

2. Direction of velocity:

The difference between speed and velocity is often a perplexing difference for students. The following student is trying to reconcile the vector velocity graph of the freefalling cheerleader with his notion of "speeding up," which usually refers to speed:

Example <831>, real-time, 1-D freefall, cheerleader:
S16 She's always slowing down. I find that strange (*{4} problem with: neg. velocity not same as "slowing down"). Her acceleration will always be negative.

Sometimes negative velocity is referred to as "lost velocity," as Goldberg and Anderson (1989) discussed. This could be a vocabulary theme:

Example <232>, delay-time, 1-D freefall, cheerleader:
I OK, and what about velocity versus time?
S7 Negative...she lost velocity, I guess (*{4} neg. vel. problem).
I What happened at the beginning?
S7 I don't know....
S3 In the beginning, she was getting thrown upwards, so her velocity was positive, meaning she was going upwards at a certain speed...(*good).
I And what happened to her velocity as she was going upward?
S3 It decreased, as gravity slowed her down. And then we got it hitting the zero point twice, which shouldn't be, but whatever is one is correct, she peaked there, and gravity is pulling her down and down, that's why she's getting a negative acceleration there (*{6} accel./vel. confusion in the last statement, but good analysis before that).
I And what does negative velocity mean?
S3 Negative velocity (*good: corrects his error) means she's going downwards.

The idea of negative velocity could be a problem with reading a graph's features, such as positive and negative coordinate values (see theme seven also). Peters (1982) noticed this in student graphs, where velocity was drawn as all positive. The following student describes and draws this type of "speed" graph (and see Figure 16):

Example <1051>, real-time, retention interview, 2-D freefall, ball:
I And what happens to the velocity?
S22 It decrease..., no..., it decreases.
I Show me.
S22 At the top, zero, but then when it comes down, it increases. Maybe it should be a curve. I don't know. Is that even close?
I Why do you say it might be a curve?
S22 Cuz, I don't think that's constant (draws positive vel. when ball going downwards: *{4} neg. vel. error).
I Go back to our idea about negative. Remember when you had this negative? (show her her posttest) Why did you make that negative?
S22 (draws correct graph) Would it just be like that?
I Why do you say that?
S22 Cuz..., well..., I don't know.... Because the top is positive and the bottom is negative.

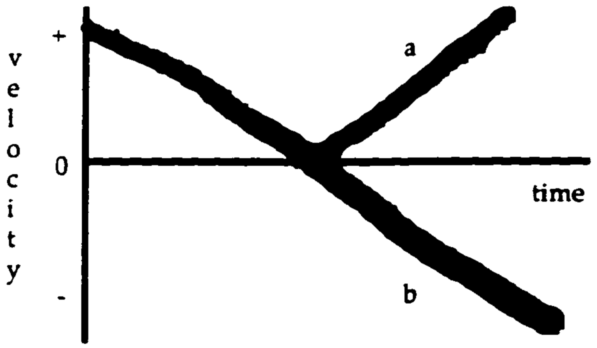

Figure 16. Real-time student 22 retention interview velocity versus time graph for ball thrown upward.

Student 22 drew graph "a" first (Figure 16), then with prompting, recalled the notion of negative velocity, and drew curve "b" correctly.

Both real-time and delay-time students had similar difficulty with negative velocity. Delay-time student 3 also recalled the correct meaning of negative velocity and its graphing characteristics after some prompting (and see Figure 17):

Example <252.9>, delay-time, retention interview, 2-D freefall, ball:

I	Go ahead with velocity.
S3	(*{4} vel. error: draws it as a peak, all positive) Wait....
I	Why did you say "wait?"
S3	I'm thinking... This is wrong.
I	Why is it wrong? Because velocity is changing, at a..., it's not constant going up, it's constant going down.
I	As drawn, what does that represent?
S3	That represents a ball, ...oh, wait....
I	Are you considering during the throw, or after it leaves the hand?
S3	I'm considering from the very beginning, ...OK.
I	On the first one, you didn't. Let's say after is leaves the hand.
S3	OK (draws v vs. t correctly). After is leaves the hand, it has a very high velocity, as compared to the rest of this graph, then it's

decreasing at a steady rate, the velocity is, so it finally hits zero, where it maxes out here (points to peak on d vs. t), and then drops back down, the negative velocity increases and increases. (*good description of v vs. t).

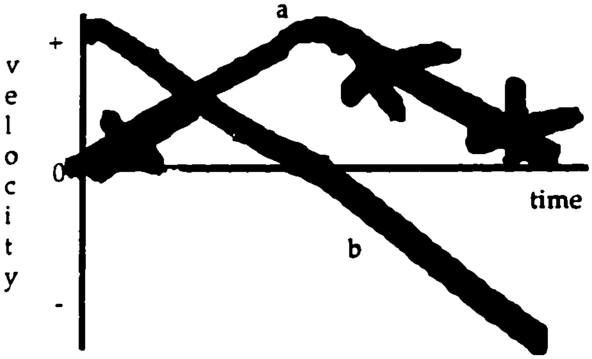

Figure 17. Delay-time student 3 retention interview velocity versus time graph for ball thrown upward.

Student 3 first drew graph "a" in Figure 17 as all positive, much like the displacement versus time graph. McDermott et al. (1987) describes this shape as "an attempt to represent on paper the reversal in direction of the actual motion in space" (p. 510), although in this example the graph would then be a "V," not an inverted "V." After crossing out graph "a," graph "b" is the student's corrected graph, which includes negative velocity.

No significant differences were found between treatment groups regarding difficulties with velocity.

Theme five—Difficulties with acceleration.

1. Direction of acceleration:

Students learn in introductory physical science classes that when a car brakes, it "slows down," and has a negative acceleration. The students then believe that all negative acceleration means "slowing down," which is the phrase they use for decreasing magnitude of velocity. However, a ball in freefall travelling downward has a negative acceleration (if downward is given the convention of negative direction), and an increasing magnitude of velocity. or as students say, "speeding up." McDermott et al. (1987) found that "this particular conceptual difficulty is persistent and impedes the progress of many students" (p. 510). Examples of students stating that negative acceleration means "slowing down:"

Example <341>, real-time, 2-D freefall, ball:
S5 Acceleration should go negative. Then it goes back....
S4 No, it should stay negative, cuz it's always slowing down (*{5} accel. error).

Later, same interview:
I What's the value of the acceleration?
S5 Negative. It's negative.
I What does negative mean?
S5,S4 Slowing down (*{5} accel. error).
S5 An overall negative acceleration, meaning that it's slowing down.
I After the peak, did the ball slow down?
S5 No, it started to accelerate again. Its speed, its vertical speed went to zero, then it started falling back down again. Re-accelerating.
I What's the acceleration being negative mean?
S5 The overall average was negative.
S4 That it was slowing down overall (still an error).
I It slowed down going up. But, you said it speeded up going down.
S4 Yeah, but we stopped right here, and its peak was right here, so there wasn't much measurement in between. But overall, between that measurement, ...
S5 The average was lower.

S4 The average of the acceleration was more of a slow-down than a speed-up (*{3} vocab.).

S5 If we would have taken the peak to be the middle measurement, it would have almost been zero. If we had taken it from here to here as five measurements, and there to there as five measurements, we probably would have gotten an acceleration of zero (*{6} still problems with accel.—want it to be pos. up and neg. down, with a zero overall, as velocity graph is).

Example <442>, delay-time, 2-D freefall, ball:

I How about acceleration?

S6 It was negative the whole time.

I Why is that?

S10 It was slowing down the whole time (*{5} neg. accel. problem)... when it did hit zero....

S6 It became less negative.

I Was it less negative going down?

S10 When it hit the final velocity..., the top...when it went to zero, then started down again, when it goes down you have negative acceleration.

I And going up, what does it have?

S10 It had negative acceleration going up, too.

I How about at the top, what was the acceleration?

S6 Still negative, but it's less negative (*{7} worried about the fluctuations in the graph, even though her explanation isn't physically correct—"slowing down the whole time"), I don't know, it's closer to zero.

S10 It's about, right about there (points to graph)...where it hit the top at, it sped up a little.

2. Acceleration compared to deceleration:

When not explicitly describing direction, students typically state that acceleration always means speeding up (i.e., ball going upward is not accelerating until it comes downward), while deceleration always means slowing down. In the next example, a student used this reasoning:

Example <252.8>, delay-time, retention interview, 2-D freefall, ball:

I OK. Acceleration.

S7 (indecision) Basically, the same as velocity (draws same as velocity *{6} accel./vel. confusion between types of graphs).

I Why is that?
S7 Because, I'm probably wrong, but, I thought it started out at zero. But, it doesn't gain any acceleration. It's not accelerating on the way up (*{5} thinks acceleration must mean "speeding up"), it's decelerating (some understanding here).

3. Discontinuous acceleration:

Transcripts revealed that students often referred to acceleration being zero or less at the top of the path of a projectile. Similarly, students have a "velocity equals zero implies acceleration equals zero" misconception. Dykstra et al. (1992) said that "velocity and acceleration are often treated as the same thing, which seems to have some bearing on the students holding the notion that when an object is 'stopped' its acceleration must be zero" (p. 638). Thus, students assume that if velocity is zero, e.g., at the top of the path of the cheerleader in freefall, or the top of the path of the basketball (vertical component only), then acceleration is zero. This could be classified as an acceleration-velocity error, since it seems the students *refer* to the fact that the velocity is zero, but they *state* that the acceleration equals zero. (see also theme six) Examples of discontinuous acceleration misconceptions (and see Figure 18):

Example <551.8>, real-time, retention interview, 2-D freefall, ball:
S11 Well, as the ball is thrown upward, gravity starts to affect it, the ball's going to be decelerating, or accelerating in the negative direction. As it reaches its highest point, then the velocity is zero. So it no longer is accelerating (*{5} accel. error, a=0 at top), or in either direction, and then, as gravity starts to affect it again, then it's accelerating in the negative direction.

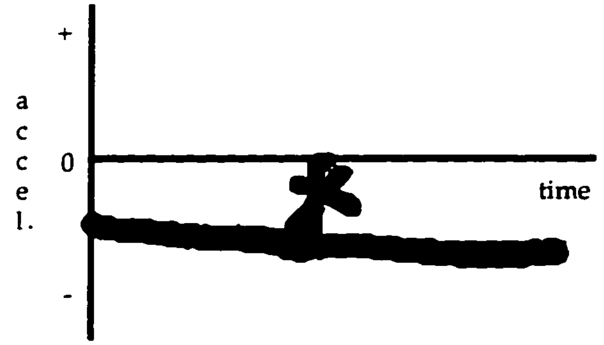

Figure 18. Real-time student 11 retention graph of acceleration versus time for a ball thrown upward.

Student 11 drew a correct acceleration versus time graph (Figure 18), except he wanted the acceleration to be zero at the top of the ball's flight. The videotape shows him pausing while he tries to determine how to get the graph to zero at t=3 seconds. He then draws a sharp discontinuity at t=3 seconds to graph his notion that v=0 implies a=0. Finally, he realizes his mistake and crosses out the discontinuity.

Other students had this misconception:

Example <1452>, delay-time, retention interview, 2-D freefall, ball:
S30 Because, well, if velocity is zero here, well, then acceleration can't be negative, or positive, it has to be zero (*{5} v=0 implies a=0 misconception).
I Why is that?
S30 Cuz, it's not going anywhere, at that point.
I What do you mean by "not going anywhere?"
S30 It's stopped.

Example <252.8>, delay-time, retention interview, 2-D freefall, ball:
S7 Because it's accelerating, the gravity is pushing down, pulling it downwards, and that makes it accelerate in the negative direction (*good), slowing it down (*{5} a=neg. means "slowing down" error).
I Can you demonstrate that on the graph (graph still wrong)?

S7 It would have to start with zero, but then when it gets to the very top there is negative, ...there is none acceleration, it's zero (*{5} a=0 at top error).
I What happens at the top?
S7 It's stopped, it stops for just a minute before it goes down. It hits its very highest point in 3 seconds.
I So, what's the acceleration at the top?
S7 Zero (*{5) a=0 error).
I What did you say the cause of the acceleration was?
S7 Gravity. Isn't gravity the same at the top (catching on?)?
I Why would you say that?
S7 Is that what you were going to ask?
I I don't know. We talked about what value acceleration due to gravity was.
S7 Yeah. Negative and positive 9.8 (*{3} no units) you mean?... The acceleration due to gravity is always just positive 9.8, but the acceleration of something in freefall can be either negative or positive, it just depends on what it is doing (*{5} neg. accel. problem).

Some students described acceleration due to gravity in freefall as changing; for example, the following student thought less velocity implied less acceleration:

Example <442>, delay-time, 2-D freefall, ball:
I How about acceleration?
S6 It was negative the whole time.
I Why is that?
S10 It was slowing down the whole time (*{5} neg. accel. problem)... when it did hit zero....
S6 It became less negative.
I Was it less negative going down?
S10 When it hit the final velocity..., the top...when it went to zero, then started down again, when it goes down you have negative acceleration.
I And going up, what does it have?
S10 It had negative acceleration going up, too.
I How about at the top, what was the acceleration?
S6 Still negative, but it's less negative (*{7} worried about the fluctuations in the graph, even though her explanation isn't physically correct-"slowing down the whole time"), I don't know, it's closer to zero.

The following example illustrates a student concept of a discontinuous acceleration, where the cheerleader in freefall "accelerates faster." This could be vocabulary problems as discussed in theme three, but the transcript also illustrates the discontinuous acceleration misconception.

Example <1432>, delay-time, 1-D freefall, cheerleader:
I OK. How about acceleration?
S30 Acceleration was kind of weird!
S26 Basically here, acceleration is decreasing as she goes up. When she starts going down, the acceleration is increasing (*{5} changing accel.—is it due to the misinterpretations of fluctuations?).
I What if you were going to take an overall acceleration, an average?... Positive, negative, zero (leading question?)?
S26,S30 Negative.
I What does that mean?
S26 That she's going faster while she's going down. She accelerates faster as gravity (*{9} gravity) pulls her down (*{5} change in accel., or *{3} vocab.: "faster" instead of greater).
I But going up, what happens to her?
S30 She slows down.
S26 Going up...she's slowing down, so her acceleration's in the negative direction. Then, coming down, she's accelerating, so going faster, so acceleration's in the positive direction. (*{5} change in accel. error)
I Is it still in the negative direction?
S30 It's still negative but...(sees her mistake in assuming accel. changes)

No significant differences were found between treatment groups regarding the difficulties with acceleration theme.

Theme six—Confusion between different types of graphs or types of physics concepts.

There are some real-time versus delay-time differences in this theme. McDermott et al. (1987) found that "some students seem to find it very difficult to accept the idea that the same motion can be represented by graphs of very different shapes" (p. 510). Transcripts revealed five type of problems (described as sub-themes) in this theme. The sub-themes, frequency table, and Mann-Whitney U statistic are found in Table 23.

Table 23. Frequency table and Mann-Whitney U test of sub-themes of theme six, confusion between types of graphs, laboratory group as unit of analysis.

Sub-themes of theme six	frequency count (mean rank)		Mann-Whitney U test	
	real-time (N=5)	delay-time (N=5)	z	p
1. Displacement/distance confusion	1 (*)	3 (*)	*	*
2. Displacement/velocity errors	2 (*)	2 (*)	*	*
3. Velocity/acceleration errors	16 (4.2)	27 (6.8)	-1.36	0.175
4. Displacement/acceleration errors	2 (*)	0 (*)	*	*
5. Displacement/velocity/acceleration errors	2 (*)	2 (*)	*	*

* frequency count too small to use this statistic.

Of these five sub-themes of theme six, each showed only a few responses except for the velocity/acceleration problems, where the real-time groups had 16 comments, and the delay-time groups had 27 comments. This difference is discussed below.

1. Displacement/distance confusion:

Introductory physics students have trouble with the concept of vectors, since few measuring devices in their everyday experiences give magnitude *and* direction. Thus, students don't distinguish distance from displacement:

Example <432>, delay-time, 1-D freefall, cheerleader:
S10 We're supposed to discuss the graphs.... Displacement is just distance travelled (*{6} distance/displ. error).
S6 (velocity) She's going pretty fast, then she slowed down to a level speed...then she's going fast in the opposite direction (*good—neg. vel., yet still problem with magnitude, see below).

However, the following student, after initially misunderstanding, grasps the concept after some thought:

Example <331>, real-time, 1-D freefall, cheerleader:
S5 Uh, oh! Her displacement went negative when she turned around.
S4 That does make sense, in a way, it does.
S5 Displacement should be all continuous, no matter what; it should never be negative (*{6} displ. error). Or, wait. Remember the one where it went all around the block (recalling a class problem), and ended up a block southeast? Her displacement was that, so, ..., let's just do another one.
S4 This is her in mid-air, I think.
S5 That's right where she started, we started.
S4 Right around here, that's where she's right up here (points to video).
S5 They threw her up, and she flipped, and came back down, and at the point where we started, is right there, and started going back down again. Cuz, she ended up lower than where we started with (*good: figured out the neg. displ. error).

2. Displacement/velocity errors:

Occasionally, students referred to velocity when they were describing displacement:

Example <212>, delay-time, 1-D constant velocity, runner:
I That might help. What's happening on the velocity?
S7 His velocity went up (*{6} confusion between types of graphs error, *{3} vocab.—"went up" instead of "increased"), really sharp.
S3 It should remain the same.
I What do you mean, remain the same, the velocity?
S3 Should remain constant.
I What do you mean, constant?
S3 Same, same horizontal line.
S7 Same velocity (*good).

3. Velocity/acceleration errors:

This sub-theme showed 43 examples from the transcripts, with 16 from the real-time groups (mean=3.2, SD=1.3), and 27 from the delay-time groups (mean=5.4, SD=3.0), a slight difference between treatment groups. However, this difference is not statistically significant. Students may be assisted slightly more by the real-time effect for the more abstract concept grouping of velocity and acceleration. Student understanding of the less abstract grouping of displacement and velocity may not benefit from the real-time effect. Some real-time responses:

Example <521>, real-time, 1-D non-zero acceleration, sprinter:
I How about the acceleration versus time?
S8 His acceleration...shouldn't it have increased (*{6} accel./vel. confusion)?
I Acceleration increased? Are we talking about acceleration or velocity?
S8 He's always constantly accelerating, but you can only accelerate so fast.

Example <1031>, real-time, 1-D freefall, cheerleader:

I That acceleration: If you were to take an average acceleration, what kind of line would be shown (too leading?)?

S18 It would be negative.

S22 I think it would be below zero.

I What does that mean?

S22 That the majority of her jump was going down (*{6} vel./ accel. error).

Some delay-time responses:

Example <642>, delay-time, 2-D freefall, ball:

I So, while the ball's in the air, what's happening to the displacement?

S14 The acceleration due to gravity increases first.... I mean it's negative 9.8, then it's negative 19.6, and so, eventually it overcomes that, and levels out, the ball's trajectory (*{6} accel./vel. error) (*{8} not discussing graph d vs. t directly). And then they start going down.

Example <252.8>, delay-time, retention interview, 2-D freefall, ball:

I OK. Acceleration.

S7 (indecision) Basically, the same as velocity (draws same as velocity *{6} accel./vel. confusion between types of graphs).

I Why is that?

S7 Because, I'm probably wrong, but, I thought it started out at zero. But, it doesn't gain any acceleration. It's not accelerating on the way up (*{5} thinks acceleration must mean "speeding up"), it's decelerating (*good—some understanding here).

Example <1252>, delay-time, retention interview, 2-D freefall, ball:

I And now acceleration.

S21 Acceleration...would be from...that's in motion, that's de-accelerating...the ball's in motion...you look at the ball, it's already in motion....

I It's already in motion.

S21 So it's constantly, the next, acceleration is going be -9.8 (*{3} units) and increasing there for every second (*{6} vel./accel. error). And then after three seconds it says the pitch...(he can't accommodate the sloped line that he drew with his notion of a constant acceleration: *{6} vel. and accel. confusion).

4. Displacement/acceleration confusion:

Students often view kinematics terms as interchangeable, without regard for accuracy:

Example <521>, real-time, 1-D non-zero acceleration, sprinter:
I	How about the acceleration versus time?
S8	His acceleration...shouldn't it have increased (*{6} accel./vel. confusion)?
I	Acceleration increased? Are we talking about acceleration or velocity?
S11	He's always constantly accelerating, but you can only accelerate so fast.
I	What if you were to take an average of all those points, what would be the value?
S8	Probably about zero.
I	How could that be?... Aren't they all above the axis?... So, what would the acceleration be?
S11	Positive.
I	Positive. What does that mean?
S8	Moving forward (*{6} displ./accel. error).
I	Moving forward?
S8	Getting faster. (*{6} vel./accel. error, guessing or knowledge?)
I	Which one, moving forward or getting faster?
S8	Moving forward.
I	Does acceleration tell you about distance/displacement?
S8	No.
I	What does acceleration tell you?
S11	Rate of change.
I	Change of what?
S11	Velocity.

5. Displacement/velocity/acceleration errors:

Some students are very casual with vocabulary use, to the point where all kinematics terms are interchanged, and seemingly used at random:

Example <521>, real-time, 1-D non-zero acceleration, sprinter:
I	What will the displacement versus time graph look like?
S8	That's right.
S11	Straight line (*error).

S8 (frown by instructor) No? Because as time increases, he's going faster and faster.
I So, what will that show on the graph?
S8 This (points to graph).
I How does that differ from last time, the distance runner?
S8 He was at a constant pace, a straight line.
I What kind of a straight line?
S8,S11 A horizontal straight line (*{6} displ./vel. confusion).
I What's the value of the displacement in a horizontal straight line? What would that tell about the runner?
S8 It's constant.
I A horizontal line, on displacement versus time, what would that tell about the runner's motion?
S8 It was constant, he wasn't accelerating (*{6} displ./vel./accel. error).
I Constant displacement means what?
S8 He didn't move if it was constant displacement.

Example <222>, delay-time, 1-D non-zero acceleration, sprinter:
I Describe this graph (d vs. t).
S3 It's a curve.
I Why?
S3 His acceleration is a constant. It's increasing (*{6} he's asked about the d vs. t, answers about accel., and then displ., or is it velocity: displ./accel./vel. error. Or vocab. error—what is "it?"). So, he's covering a greater distance in the same amount of time.

In general, student understanding regarding the relationships between kinematics graphs and concepts was not improved by the real-time effect. There was a slight difference between treatment groups regarding the relationship between the velocity versus time and acceleration versus time graphs, where the real-time group had fewer errors.

Theme seven—Misconceptions about shape or starting point of graph.

Real-time groups had 11 errors and delay-time groups had 17 errors referring to the starting point or shape of the graph. The only notable difference found between treatment groups in this theme was with difficulties regarding fluctuations of graphs.

1. Fluctuations of graph:

Transcripts revealed that some students wanted to describe every little bump on each kinematics graph. Data taken from a videodisc have many sources of error, such as the film speed of the recording, the parallax problems of the videoscreen/acetate system, and student reading of the scaling. Thus, the graphs resulting from this data have many irregularities. Our physics textbooks invariably have smooth, perfectly linear or parabolic curves representing motion. Students then believe that all kinematics graphs are smooth. Thus, a realistic graph is difficult for them to interpret. Romer (1993) said that laboratories "remind us of the elementary but easily forgotten fact that physics deals with the real world of natural phenomena.... Experimental data are imperfect, subject to errors and uncertainty; graphs that 'should be' straight lines are never exactly so" (p. 134). When using a MBL to display cooling curves, Nachmias and Linn (1987) found that "efforts to explain that the physical curve was smooth even though the observed curve was jagged created confusion in the class" of eighth-graders (p. 500).

The students in this study were often told during the treatments to ignore the small fluctuations, and assume it was a fairly smooth curve; i.e., they were told to look at the overall trend of the graph. Despite this advice, real-time groups had four fluctuation comments, and delay-time groups had eleven fluctuation comments. Real-time students may be more attuned to the overall motion of the object by seeing it simultaneously with the graph production. Thus, they do not attend to a small fluctuation in the graph. Delay-time students may try to recall details of the motion, then try to mentally recreate the motion as the graph is being produced. Thus, they assign a physical description to each fluctuation. These data suggest that students in the real-time group were less concerned with the details of the graph. They were possibly more attentive to the overall trend of the graph instead.

Example <831>, real-time, 1-D freefall, cheerleader:

I OK. Tell me about acceleration.

S16 She has a negative acceleration the entire time. Which would be logical...her acceleration is the greatest at the very beginning, when the guys push her upward. And from then on, her acceleration...here she's starting here, and she's accelerating, and she's getting faster and faster...Here I think she's starting to slow down, before she goes into her flip. And then here where she starts to pull her waist up and flip, that's why I think that's steady right there. Because her waist doesn't really move much, because as she's coming down her waist is coming up. And right here, I think is a drastic drop off because both she is falling and her waist is coming in a downward motion (*{7} he's concentrating on fluctuations of the a vs. t graph—problem with real analysis, not the perfect graphs you see in texts).

I Overall, what about the acceleration, if you were to take an overall average acceleration?

S16 It's entirely negative.

I Which means...?

S16 She's always slowing down (*{5} accel. misconception), she's always going slower than she was before.

I Right before they caught her, she was slower?
S16 Actually she was quicker, but she was going in the opposite direction. Her acceleration was always downward.

However, some students noted fluctuations that *did* have meaning physically. For example, the following student noticed that the sprinter's motion did not exhibit uniform acceleration, due to the inherent irregularity of human running:

Example <311>, real-time, 1-D constant velocity, runner:
S5 Look at that. Bad! They are doing it as he is running (*{1} noting real-time effect). He's running and accelerating and decelerating. Like every time he jumps off, boom, boom, boom (*good—noting fluctuations in graph caused by human running motion). OK, velocity vs. time.

Real-time groups had seven errors and delay-time groups had six errors referring to the starting point or shape of the graph (non-fluctuation errors). Errors include:

2. Starting point of graph:

Students often want graphs to start at zero. For example, a ball thrown upward has an non-zero initial velocity while in freefall, yet students start the velocity versus time graph at v=0 (see Figures 8, 9, 10, 12 and 13). They may be thinking that the ball is still in the hand of the thrower, and not in freefall yet, but most students start the graph at zero because "graphs are supposed to start at zero," or most graphs they see *do* start at zero. A retention interview illustrated this point:

Example <551.9>, real-time, retention interview, 2-D freefall, ball:
I And what's happening to the velocity?
S8 Increasing (*{4} vel. problem).
I So, after it leaves your hand, the velocity is increasing?
S8 Uh, huh. Then it starts to decrease as it nears its peak.
I What causes it to increase?
S8 The force of your hand.
I What happens after it leaves your hand?

S8 Air resistance and gravity (*{9} dynamics) starts to pull at the ball.
I But it's still increasing its speed?
S8 Right, until, ...it, ...well, ...for a while, ...I guess it's decreasing (*good—finally realizes a mistake).
I After it leaves your hand?
S8 Yeah.
I Why do you say that?
S8 For a while, because, once it reaches zero, ...it goes from whatever velocity your hand's thrown the ball with to zero.
I Can you show that on your graph?
S8 Like that (*{7} now draws a downward loop—insists that graph starts at zero, then draws an upward loop). But then the velocity increases, goes from zero (*good—notices contradictions).

3. Sharp changes in graph not physically possible:

Students demonstrated many examples of discontinuities in kinematics graphs. McDermott et al. (1987) described students who had similar problems, where "a kink or cusp indicates an abrupt change in speed that does not occur in the actual motion" (p. 509). For example, Figures 4 and 8 show cusps on a displacement graph and a velocity graph when a peak is drawn as the ball reaches the top of the graph. Figures 10 and 11 show sharp discontinuities to unsuccessfully explain a change in direction of velocity. Figures 14 and 15 demonstrate step discontinuities for acceleration. The following student describes her thinking concerning this type of discontinuity, with her graph shown in figure 19:

Example <252.8>, delay-time, retention interview, 2-D freefall, ball:
I OK. Velocity, what happens to velocity in the upwards direction?
S7 (draws v vs. t just like d vs. t) It's gaining velocity, you throw it up, and at first, it's got a lot of velocity (she's pointing to the graph, *{10} misreading graph increase as high velocity—slope/height error) in the first part of the toss, it's got more velocity, and then as it reaches the peak of its height, ...no, wait (*good—realizes her error) it has zero velocity at the very top!

I How can you show that?

S7 So you have to go all the way down (*{7} non-continuous graph to try to correct her error), ...I don't see how that could be, there should be no sharp edges (*good), but it has zero velocity.

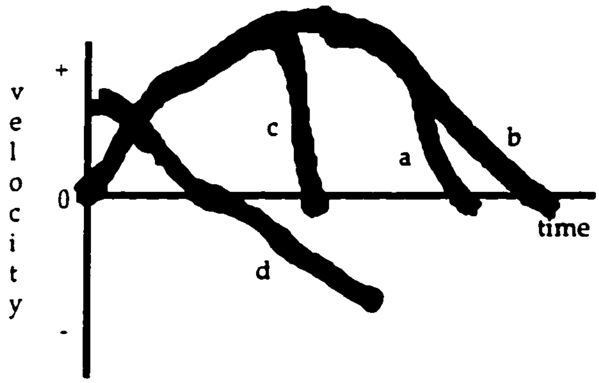

Figure 19. Delay-time student 7 retention graphs of velocity versus time for a ball thrown upward.

As seen in Figure 19, student 7 first started graph "a" at zero, then drew it much like the displacement graph. Then she tried to correct the graph to make it end at t=6 seconds as shown in "b." Next, she realized that the velocity at t=3 seconds must be zero, so she drew a sharply decreasing velocity. Finally, she realized her mistake and drew the (generally) correct graph "d."

4. Students don't give value of graph (+, -, or 0), or mis-read values of graph:

When asked to give the average value of an acceleration versus time graph—positive, negative, or zero—students often misunderstood. Leinhardt et al. (1990) pointed out that "students often narrow their focus to a single point even though a range of points (an interval) is more appropriate" (p.37). The following transcript is typical of students who have difficulty giving the value of a graph:

Example <422>, delay-time, 1-D non-zero acceleration, sprinter:
I How about the acceleration versus time?
S10 After he (she) got out of the blocks, he accelerated really quickly, then he started to slow down a lot, for a while there, a very lot, then picked it up some more (*{7} fluctuations).
I If you were to take an average acceleration, what type of value would you get?
S6 It wouldn't be that big, because it's got an extreme high and an extreme low, and its got a lot of in-betweens.
I If you were to pick an average, where would it be? (*{7} I'm wanting positive or negative or zero, but they don't get it)
S10 I think it would be right in there somewhere (points to positive on graph).
I Which would be what kind of value?
S10 Positive.
S6 Yeah, positive.
I Which means what, about the sprinter?
S10 He did accelerate (*good).

5. Students misstate the shape of graphs:

As any physics teacher has experienced, students have difficulty with describing common kinematics graphs in terms of the shapes of the graphs; i.e., linear, parabolic, or inverse. The following students both describe the sprinter's displacement versus time graph as linear, when it is parabolic (as seen in Appendix A, sprinter's graphs):

Example <1021>, real-time, 1-D non-zero acceleration, sprinter:
I What'd you get for displacement?
S22 It's pretty constant (*{3} vocab.—wrong meaning of constant).
I Displacement is constant?... What is the shape of the graph?
S22 It's an upward slant, but it's a constant, it's constantly going up (*{3}—vocab.) at the same...I mean it's not, like, connected or anything....
I What is the shape of the graph?
S22 Almost a straight line (*{7} should say curved or parabolic).
I What does that mean?
S22 You can figure out slope from it (*{10} slope), the straight line.

I How does it compare to last time, with the distance runner?
S18 This one is a sharper rise. The distance runner, didn't it go more like that (traces a line with small slope; *good idea, but still should notice the curved shape)?

Example <521>, real-time, 1-D non-zero acceleration, sprinter:
S8 (to instructor) Isn't this supposed to be going in an upward straight path?
I What do you mean?
S8 A sprinter, as his time increases, he's going at a greater speed. Constantly.
I What will the displacement versus time graph look like?
S8 That's right.
S11 Straight line (*{7} error—should be parabolic).

6. Students more comfortable with spreadsheet numbers than with an abstract graph:

Some students seem to be more at ease with an actual numeric example, rather than a trend on a graph, or a functional relationship. The following student demonstrates this idea, in addition to having difficulty reading positive, negative, or zero from the graph as discussed above:

Example <222>, delay-time, 1-D non-zero acceleration, sprinter:
I OK, what about acceleration (graph)?
S3 I don't know why it did that.
S7 I don't know either.... You had a negative acceleration at the end....
I How about if you took an average acceleration? What would it be?
S3 Oh, it says...can I go back to look at them on the spreadsheet (*{7} more comfortable with numbers than with graphs)?
I From the graph.
S3 Average acceleration is pretty close to zero, isn't it (*{7} value of graph error—should be positive)?
I Where is it in relationship to the horizontal axis?
S7 Above.
I Above? Which means what kind of acceleration?
S7 Constant acceleration, it would be a constant acceleration.
I What sign would it be? What's the sign of the acceleration?

S3 Positive.

In summary, real-time students and delay-time students had similar errors and misconceptions regarding the shape or starting point of kinematics graphs. However, real-time students had slightly less of a tendency to attend to fluctuations in graphs than delay-time students.

Theme eight—Students wanted to ignore graphical abstractions in favor of giving a physical description, or a memorized definition.

Physical analysis, not graphical analysis used:

It is good to use a physical analysis, but some students, when not understanding what the graph is abstractly representing, choose to describe the physical event, and ignore, or not discuss the graph. This could be intuition, which Leinhardt et al. (1990) described as "features of students' knowledge that arise largely from everyday experience" (p. 24). Students could use this intuition to describe the event, which they understand, but ignore the graph, with which they are not comfortable:

Example <1011>, real-time, 1-D constant velocity, runner:
I OK, tell me about the displacement-time graph.
S22 It goes up...constant.
I Constant what?
S18 Speed.
S22 It's like, constant going from A to B, the direction. Isn't this displacement? The line that takes to get to...like if the runner was going like this (up and down motion), then displacement would be from A to B (*{8} she's using the class definition of displacement and working from there; she is not attending to the physical event, nor the graph).
S18 He's just running at a regular speed, a constant speed.
S22 I think it would be staying on a line.
Later, same interview:
I OK, what about acceleration?

S22 He didn't accelerate that much.
I Why do you say that?
S22 Because he's a distance runner (*{8} physical analysis, not graphical).
S18 So he stays right around the average speed.
I How does that...describe that on the graph.
S18 Isn't that, like, the average, or something (pointing to graph)?
I What is its value (*{7} pos, neg, zero—have trouble reading graph)?
S22 Its value?
I 500?
S18 What?
I Negative 56?
S22 Where did you get those numbers? He doesn't accelerate very far (*{6} displ./accel. error).
I What value tells you that?
S18 Whatever that is right there (points to graph).
I What is that?
S22 The average acceleration?
I Is it zero?
S18 Oh!

Example <612>, delay-time, 1-D constant velocity, runner:
I So, why does the displacement-time graph look the way it does?
S14 Because there's hardly any acceleration, either positive or negative (*{8} he's jumping ahead. He's not answering the question using the graph data).
I And, that will produce what kind of graph?
S14 Straight line.

Same student, later treatment <642>, delay-time, 2-D freefall, ball:
I So, while the ball's in the air, what's happening to the displacement?
S14 The acceleration due to gravity increases first.... I mean it's negative 9.8, then it's negative 19.6, and so, eventually it overcomes that, and levels out, the ball's trajectory (*{6} accel./vel. error) (*{8} not discussing graph d vs. t directly). And then they start going down.

No differences were noted between treatment groups regarding this theme.

Theme nine—References to dynamics.

Note: even though the thrust of this research is on kinematics, the topic of dynamics invariably came into student analysis.

1. Force misconceptions:

Some students believe that constant velocity requires a constant force. Sometimes this is called a "residual force" error, or historically it is "impetus." Thijs (1992) described this misconception as "a force inherent to the object ('impetus')" (p. 165). Students believe that as the object "runs out" of this force, the object will decrease its speed and eventually stop.

Example <1242>, delay-time, 2-D freefall, ball:

I Tell me about velocity-time.

S21 Basically the same, it's measured from the horizontal position, so therefore the force it receives is going to continue moving in that direction (*{9} dynamics error); there is no negative velocity the other way. It's going to continue at that same velocity.

Later, same interview:

I Does that acceleration graph support your statement?

S21 Yeah.

S24 It's going to have a greater change in speed as it's moving up to the peak. When it reaches the peak right here, which also agrees with the zero velocity, the acceleration will be smaller, because there's less change, because it's fighting with the initial force that propelled it and gravity (*{9} dynamics error, *{5} accel. changing error. He has created an alternate conception that makes logical sense to him). It balances out at the peak of the throw, which is right here. The acceleration is a lot slower there, because the gravity has gotten close or has, at the peak, overcome the initial force that the ball was thrown upwards at.

I The ball contains a force of gravity, and another force?

S24 You have two forces acting on the ball, you have the initial force that the guy gives it when he throws it, and the force of gravity pulling it down throughout. Until it reaches the peak, the force that he gives it is enough that it outweighs gravity (*{9} dynamics error), it has more force than gravity trying to pull it down. When it reaches the peak, those two forces are...stabilized, I guess, and when it's pulled back down, it's pulled back down by the gravity.

Minstrell and Stimpson (1986) found that students use the idea of "force of motion that will just sustain the constant velocity" (p. 12):

Example <642>, delay-time, 2-D freefall, ball:
I So, what does that describe, that graph (d vs. t)?
S14 It's describing its vertical motion. What it's doing is at the point were the vectors level out (what is meant here?), and it's all horizontal, is where it peaks out, then it starts going downwards, cuz the gravity (*{9} dynamics) starts being the more powerful of the two forces (*{9} force problem). It goes downward.
I When the ball was in the air, what were the two forces?
S14 Gravity versus forward motion.
I Forward motion's a force?
S14 It's forward motion's...has got direction, it's forward. I mean, it's positive.
I What's positive?
S14 OK, so the sign would be...positive would be up this way (draws on acetate), and negative would be here and here (draws Cartesian coordinate).

2. Gravity comments:

Students usually refer to gravity in describing kinematics graphs of freefalling objects. Berg and Brouwer (1991) describe student misconceptions regarding gravity. Some students have unusual interpretations of the force of gravity:

Example <1041>, real-time, 2-D freefall, ball:
I OK. And acceleration.
S18 Negative acceleration—gravity is pulling it down (seems to memorize this response—does he understand?).
I Ok, on the way up?
S18 Still negative.
I At the top?

S18 That's when it's the lowest negative (*{5} accel. less at top), cuz then gravity has a bigger pull (*{9} gravity problem—more pull on the way down).
I What's lowest?
S18 At the top, right there (points to a vs. t at t=0), when it said the peak of the shot, it's got the lowest negative acceleration (*{5} is he noting the fluctuation on the a vs. t graph, or is it a a=0 at top problem?).
I What changes at the top?
S18 What do you mean?
I Does gravity change at the top?
S18 No.
S22 The direction (*{6} accel./vel. error, or is she referring to vel. only?).
I If we had a smooth curve, what might it appear to be?
S18 Sort of like a wave. If it was a smooth curve.
I Probably straight.
S22 Straight?
I What would that mean?
S18 Just constant acceleration.

3. Is the graph describing the ball while it is still in the hand, or after it had been released?:

As noted before, some problems with graphing a freefalling object may be that the student is describing the motion of the object while an external force is still being exerting a force; i.e., when the object is not yet in freefall. If the teacher does not specifically describe the desired starting time of the graph, the student may be describing a different situation than what is desired:

Example <1452>, delay-time, retention interview, 2-D freefall, ball:
S30 Vertically upward in 3 seconds.
I OK, explain that.
S30 You throw it up in the air, and, well, it goes up to a certain distance. And then it stops going, and gravity begins to pull (*{9} gravity) it back down like this.
I OK. And how much time did that take, for the whole trip?
S30 Probably six seconds.
I Why is that?

S30 Well, you're pushing it up, so it is accelerating up (*{9} dynamics—not released vs. released from the hand), but then gravity is pulling it back down. I guess it doesn't say how strongly you threw it up. He would have to throw it up at, ...9.8 m/s or something (*{6} accel./vel. confusion).

I (I should have followed up that last statement) OK. Let's go on to the velocity vs. time.

S30 OK. Velocity....

I And let's consider after it leaves your hand.

S30 Hmmmm? Ohhh! (wants to start at v=0) Well...is it zero as it leaves his hand?

I Consider as the ball is leaving the hand. Make the graph from there.

S30 But, I mean, after the ball leaves the hand is here (points to v=0) (wants guidance)?

I What does that mean?

S30 Hmmm. Alright (draws the v vs. t correctly, except for a slight plateau at peak).

4. Air resistance comments.

Here, another student has a "residual force" problem, and also believes air resistance is the main cause of the negative acceleration of the ball:

Example <252.8>, delay-time, retention interview, 2-D freefall, ball:

I After the ball leaves the hand, what is it doing?

S7 It's accelerating upwards (*{9} many students have this trouble—think it's accelerating up after it leaves the hand. Are they still thinking it's in the hand, or do they think a 'residual' force is acting on it—dynamics problem?), it's gaining velocity.

I After it leaves the hand?

S7 Just for a minute, yeah.

I What's causing it to gain velocity after it leaves the hand?

S7 It should be losing, because air resistance would be slowing it down, that's why it reaches the top it has no velocity (*{9} air resistance, not gravity). So, then it would be negative, it would begin negative (*{4} neg. vel.).

Both treatment groups had similar results regarding the references to dynamics theme.

Theme 10—References to slope or calculus.

This course was an introductory, high school level course, so the notion of slope of the displacement versus time graph as being the velocity at that time was very new to the students. However, several mentioned slope. Some students taking calculus concurrently even mentioned the slope of the tangent line, or the derivative. Real-time groups mentioned slope or calculus five times, and delay-time groups mentioned them 17 times. These delay-time responses came predominantly from two groups, of which all students were concurrently enrolled in calculus class. No significant differences were found between treatment groups.

1. Slope comments:

McDermott et al. (1987) described "discriminating between slope and height," and "interpreting changes in height and changes in slope" (p. 504) in their work. Student examples include:

Example <1641>, real-time, 2-D freefall, ball:
I	On the way up, what's the ball's velocity doing (v vs. t)?
S31	OK, it's like it's slowing down...right there...as the ball drops it becomes negative velocity, cuz it's going down, its steeper here because it's a high velocity (*{10} slope-steeper).
I	What does negative velocity mean?
S31	Velocity down, it's heading downwards.

2. Calculus comments:

Some students concurrently enrolled in calculus related their mathematical knowledge well to this kinematics application:

Example: <252.9>, delay-time, retention interview, 2-D freefall, ball:
I	And why is that (d vs. t graph drawn correctly)?

S3 You're throwing the ball upwards, so its initial velocity is going to be great at the very beginning. You represent that with a large slope along here (*{10} slope). It will be accelerating upwards (*{6} vel./accel. confusion—top scoring student). This will be gradually slowing down, ...acceleration will be gradually slowing down (*{6} vel./accel. error) as it approaches its highest point which is at three (seconds?) where is levels off, and the slope of the tangent line there is zero (*{10} slope, and calculus), which means its velocity is zero, and its acceleration, its acceleration, ...sorry, I didn't mean that, ...its velocity is zero (*good catching of his own mistake). Then the ball will come back down with a slow velocity at first, which is represented by these lesser sloped tangent lines (*{10} slope and calc.), and then greater as it comes back down.

Continuity of themes throughout treatments

Do misconceptions persist for a particular group or student as they go from scene to scene, or are some misconceptions created, continued, and/or dispelled from the time of treatment one to the time of treatment four or the retention interview? Posttests, treatment transcripts, and retention interview transcripts from each group and individual were analyzed for such concept continuity. Misconceptions were found to be consistent throughout the research, giving evidence to the "firmly attached" nature of them. The frequency of some misconceptions was found to increase as the treatments progressed, but this was attributed to the type of treatment. For example, more acceleration misconceptions were found in later treatments, since treatments three and four dealt with the acceleration of a freefalling object travelling upwards and downwards, a more conceptually challenging idea than the acceleration of a distance runner or a sprinter travelling in one direction only.

Summary

Posttest results and qualitative analyses showed no statistically significant differences between real-time students and delay-time students regarding kinematics graphing.

However, some noteworthy data were obtained in five areas: a) real-time students were aware of the real-time effect, and seemed motivated by it, b) real-time students decreased their eye movement between computer screen and video screen as subsequent graphs were produced, c) real-time students demonstrated more discussion during graphing than delay-time students, d) real-time students displayed less confusion between velocity versus time and acceleration versus time graphs than delay-time students, and e) real-time students did not attend to minor fluctuations in graphs as much as delay-time students.

All other data corroborate previous finding in kinematics graphing research, with no other notable differences found between treatment groups.

Chapter V—Conclusions

Introduction

This study investigated student understanding of kinematics graphing. Brasell's (1987a) research in microcomputer-based laboratories concluded that producing a kinematics graph in real-time (i.e., plotting the graph simultaneously with the motion of the object) produces significant learning gains as compared to delay-time graphing (i.e., plotting a graph some time after the motion of the object). In another study, using computer animation of videotaped images, Beichner (1990) concluded that the real-time effect is not a significant variable in improving student understanding of kinematics graphing.

This study compared real-time versus delay-time graphing of the motion of objects as displayed from a videodisc. The main hypothesis stated that students would achieve significantly better understanding of kinematics graphing if real-time graphing was used as compared to delay-time graphing. The hypothesis was not supported. However, some evidence was found that suggests that the real-time effect may have some advantages.

Quantitative research results

Real-time is not the critical factor, but it may be one of several important, interacting factors:

This research provided evidence that real-time graphing is not a dominant factor in assisting student understanding of kinematics graphing as compared to delay-time graphing. Posttest scores, as well as displacement, velocity, acceleration, and mixed question subscores demonstrated that real-time students scored slightly higher than delay-time students, but the difference was not statistically significant. This result corroborates Beichner's findings, and does not support Brasell's findings.

Both previous studies used a single laboratory period as the treatment time. This research used four laboratory investigations over a three-week period; thus, the chance for novelty effects was reduced. In addition, this time frame provided a more realistic instructional methodology; thus, the results of this research are probably more generalizable than previous works.

No gender differences in posttest scores were found, nor was there an interaction between treatment group and gender. No significant differences in posttest scores were found using the laboratory group of two as the item of analysis.

Qualitative research results

This study used interviews to probe student understanding of kinematics graphing. These interviews were videotaped and transcribed. The transcripts provided a rich source of qualitative data to assess student use of the courseware and to analyze student conceptions of kinematics graphing. Analysis of student transcripts revealed several points:

1) Real-time as a motivating factor:

Students using real-time graphs were more animated and discussed the graphs more extensively that the delay-time students, though these differences were not statistically significant. This suggests that students saw the link between the event and the kinematics graph that describes the event. However, this link did not seem to produce statistically significant learning gains as compared to delay-time students. In addition, students referred less to the real-time effect as treatments continued, suggesting that part of this motivation increase could be due to a novelty effect.

2) The use of two screens was problematic:

Due to cost considerations, two screens were used in the computer system: the videodisc monitor, which showed the video sequence, and the computer monitor, which showed the graphs. This system was troublesome for students to use, since they had to move their heads back and forth to view the real-time effect. In addition, students reduced the amount of eye movement as subsequent graphs were drawn, suggesting that they kept a mental image of the motion sequence of the object while concentrating on seeing the graphs drawn on the computer monitor. Thus, students may not have taken full advantage of the real-time effect when using two screens.

However, one screen was used in Beichner's study to display both a simulation of motion and graph, with similar results to this study; i.e., the real-time effect was not significant. Brasell's research used one screen, but she used a person as the object of study, not a video image. This kinesthetic nature of MBL tools has been hypothesized as one of the contributing features to the success of MBL materials with regard to kinematics graphing, but this has not been tested.

3) Corroboration of previous misconceptions:

Many misconceptions of kinematics graphing were observed. The results of McDermott et al. (1987) regarding viewing graphs as pictures, difficulties with negative velocity, difficulties with acceleration, confusing types of graphs, representing continuous motion, matching narrative information to a graphical representation, and interpreting slope were all corroborated in this study.

4) Use/misuse of vocabulary:

More studies are emerging of student use of language in physics. The misuse, or incomplete use, of vocabulary was demonstrated throughout the transcripts. In particular, the transcripts revealed the use of "up" or "down" as referring to magnitude at times, and as referring to direction at other times. Student communication and student understanding may be enhanced by using "upwards" and "downwards" for direction, and "increase" and "decrease" for magnitudes of quantities.

Students also misused the word "constant." At times, they use "equal" or "the same" when "constant" would be more accurate and/or descriptive. In addition, students used "speed" instead of "rate" to describe a mathematical relationship, and used "faster" instead of "greater" to describe a larger quantity. More care in the use of vocabulary could produce better understanding of the fundamentals of physics.

5) Graph fluctuations:

Students in both treatment groups were distracted by the fluctuations of the graphs. These fluctuations were produced due to the original video recording of the event, the "acetate on the screen" method of data collection, or the scaling of data. The real-time students seemed less distracted by these fluctuations, suggesting that they believed each "bump" was an insignificant feature of the graph. This might imply that the real-time effect might cause students to attend less to the details of the graphing process, and more to the overall trend of the graph.

6) Slightly less velocity/acceleration graph confusion by real-time group:

Transcripts demonstrated that real-time students showed less confusion between velocity and acceleration, though the difference was not statistically significant. In addition, real-time students showed less of a tendency to draw the acceleration graph identical to the velocity graph. This may mean the students benefit more from the real-time approach as the level of abstraction increases. This conclusion is tentative, due to very few data points.

Recommendations for instruction

Software: Costs of single screen computer systems are decreasing, so further courseware should avoid this two-screen problem, and place the videodisc recorded motion on the same screen as the graph. Software that would allow students to mark the position of the object on the screen via mouse, instead of the acetate/ink-marker system, would speed data gathering from a videodisc system, thus providing the opportunity for students to analyze more phenomenon per time. The ability to rapidly collect and display a variety of data seems an inherent advantage of MBL systems at this time.

Kinematics Graphing Skills: Real-time graphing should continue to be used, since it does seem to have some advantages, though the significance of the advantages is still under question. Instruction should focus specifically on student misconceptions, since real-time alone does not seem to dispel misconceptions as some research has indicated. Curriculum should be specifically designed from physics education research results, as McDermott (1991) has advocated. Care should be taken to specifically and patiently address misconceptions head-on, as Arons (1990) has emphasized, without the wish to "cover the material" taking priority over the need to assist students' conceptual learning.

Future research

Future research regarding kinematics graphing may involve kinesthetic research: does getting the whole body involved help students to learn the abstract concept of kinematics graphing? MBL research has hypothesized that this kinesthetic component is one reason for the learning gains of students, but studies have not isolated this variable to test its efficacy in producing student learning. Is a combination of the real-time effect, kinesthetic involvement, and the ability to produce many graphs per time the reason for the success of MBL materials, and not any one particular effect?

This research showed real-time students to have slightly better understanding of the differences between velocity versus time graphs and acceleration versus time graphs. Do advantages from real-time analyses increase as the level of physics concept abstraction increases? Future research may further investigate this idea.

Advances in video technology, such as QuickTime for the Macintosh, or Digital Video Interactive (DVI) may provide additional tools for real-time analysis of physical phenomenon. Further research should investigate these technologies.

Larger sample sizes and greater treatment times are needed in research. Early research on the real-time effect used a one-laboratory, one-class period for a treatment time. This research used four class periods over three weeks for the treatment time, yet this is still a short time to determine the effects of instruction. Larger sample sizes are also needed to improve the generalization of these research results.

Conclusion

The everyday-life examples that videodiscs can provide to physics instruction may help students to connect physics to the "real world." Real-time analysis has shown mixed results in assisting students to understand the graphical relationships of physical phenomenon. The use of videodisc systems with real-time analysis shows some promise for assisting students in learning kinematics graphing skills.

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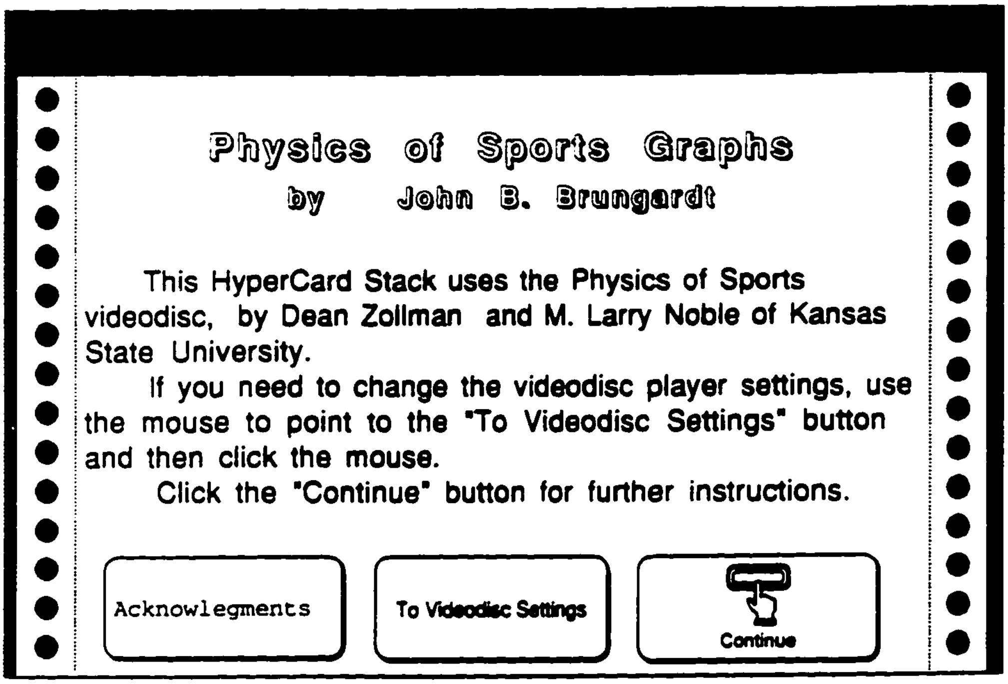
Appendix A—Physics of Sports Graphs Software

This appendix contains screen dumps of the software used in the treatments.



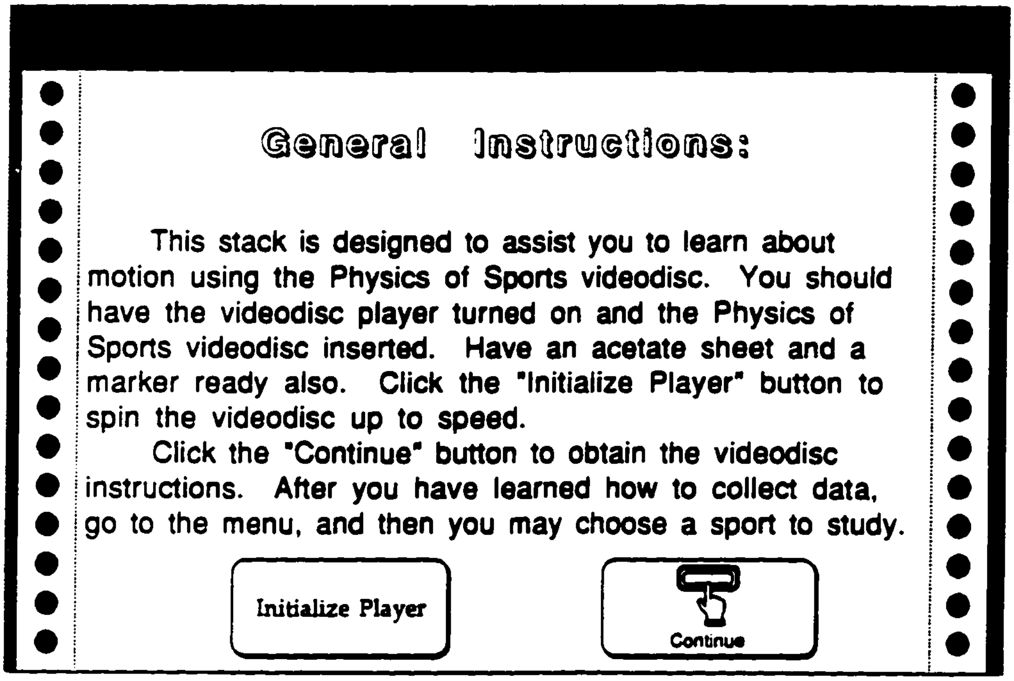
Physics of Sports Graphs

by John B. Brungardt

This HyperCard Stack uses the Physics of Sports videodisc, by Dean Zollman and M. Larry Noble of Kansas State University.

If you need to change the videodisc player settings, use the mouse to point to the "To Videodisc Settings" button and then click the mouse.

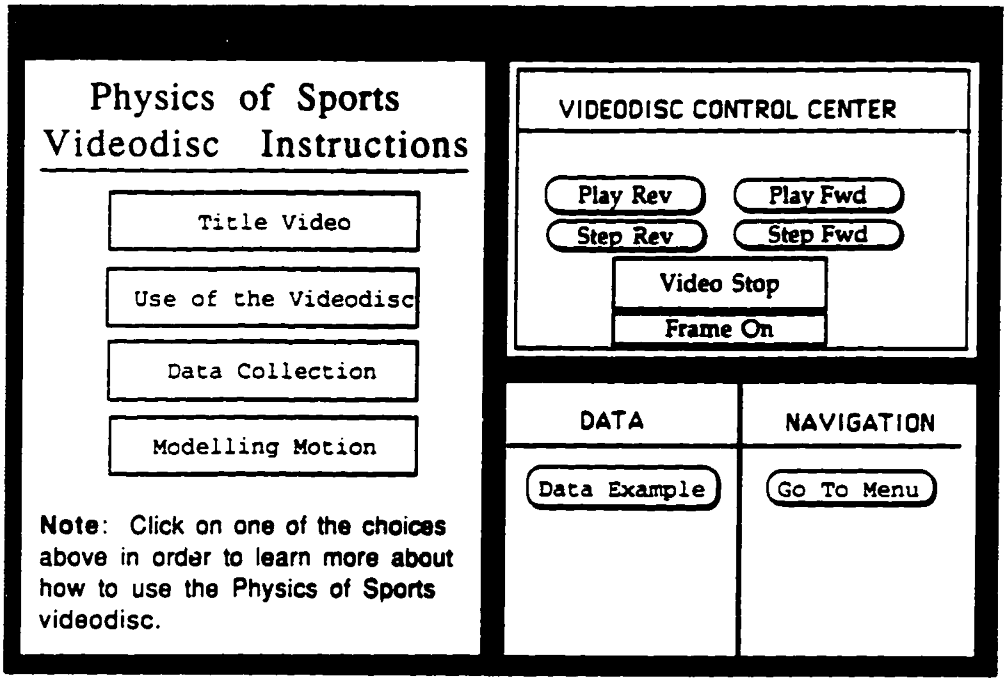
Click the "Continue" button for further instructions.



General Instructions:

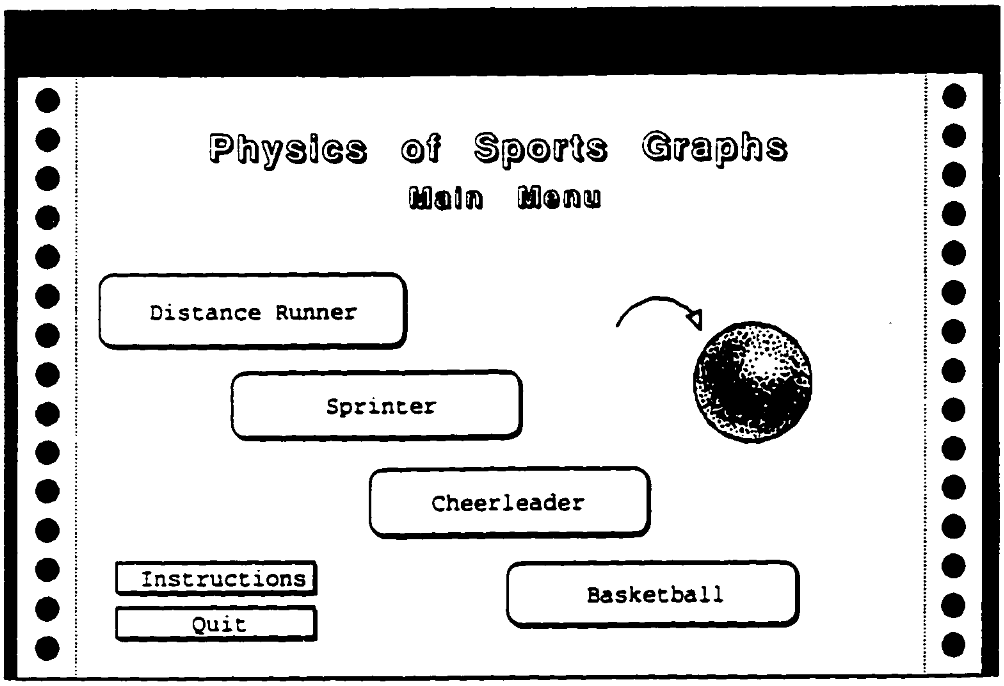
This stack is designed to assist you to learn about motion using the Physics of Sports videodisc. You should have the videodisc player turned on and the Physics of Sports videodisc inserted. Have an acetate sheet and a marker ready also. Click the "Initialize Player" button to spin the videodisc up to speed.

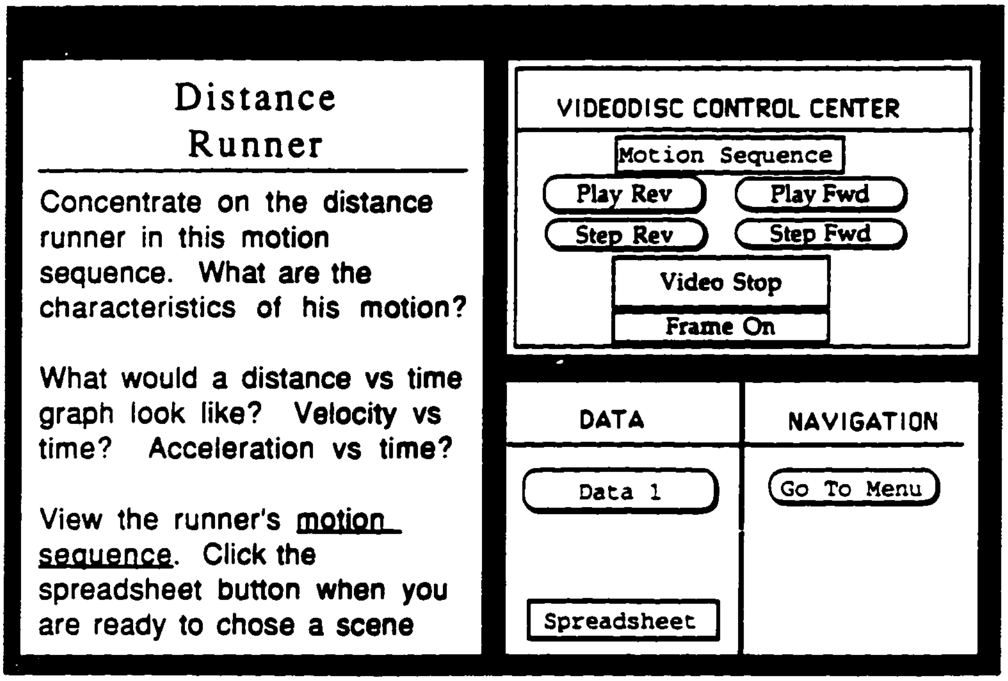
Click the "Continue" button to obtain the videodisc instructions. After you have learned how to collect data, go to the menu, and then you may choose a sport to study.



Physics of Sports Videodisc Instructions

Note: Click on one of the choices above in order to learn more about how to use the Physics of Sports videodisc.


Physics of Sports Graphs
Main Menu
Distance Runner
Sprinter
Cheerleader
Basketball
Instructions
Quit

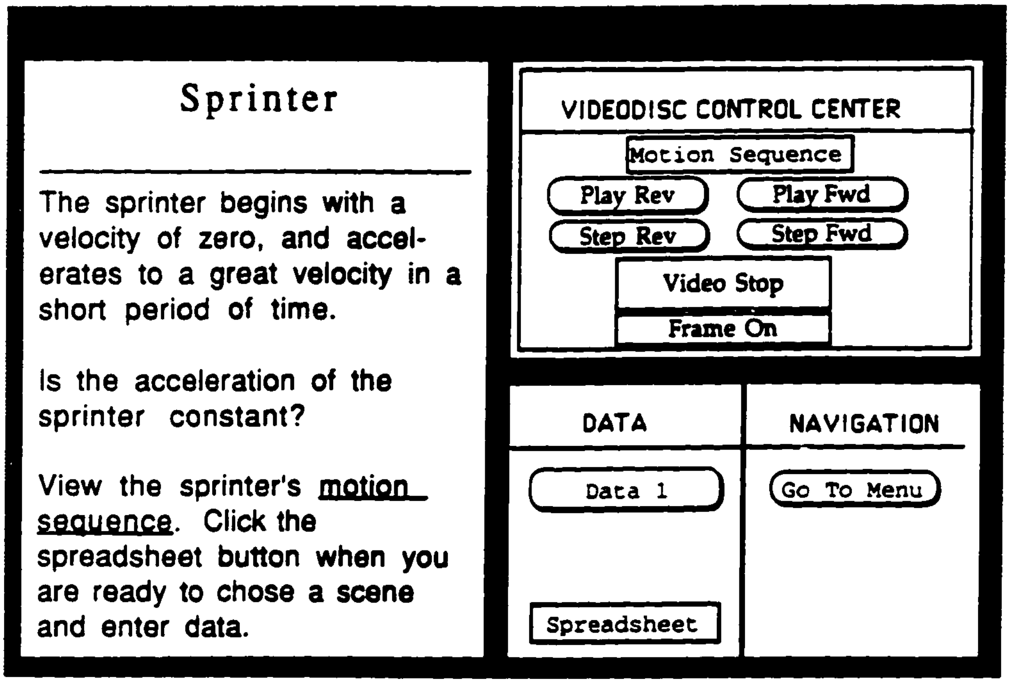


Distance Runner

Concentrate on the distance runner in this motion sequence. What are the characteristics of his motion?

What would a distance vs time graph look like? Velocity vs time? Acceleration vs time?

View the runner's motion sequence. Click the spreadsheet button when you are ready to chose a scene

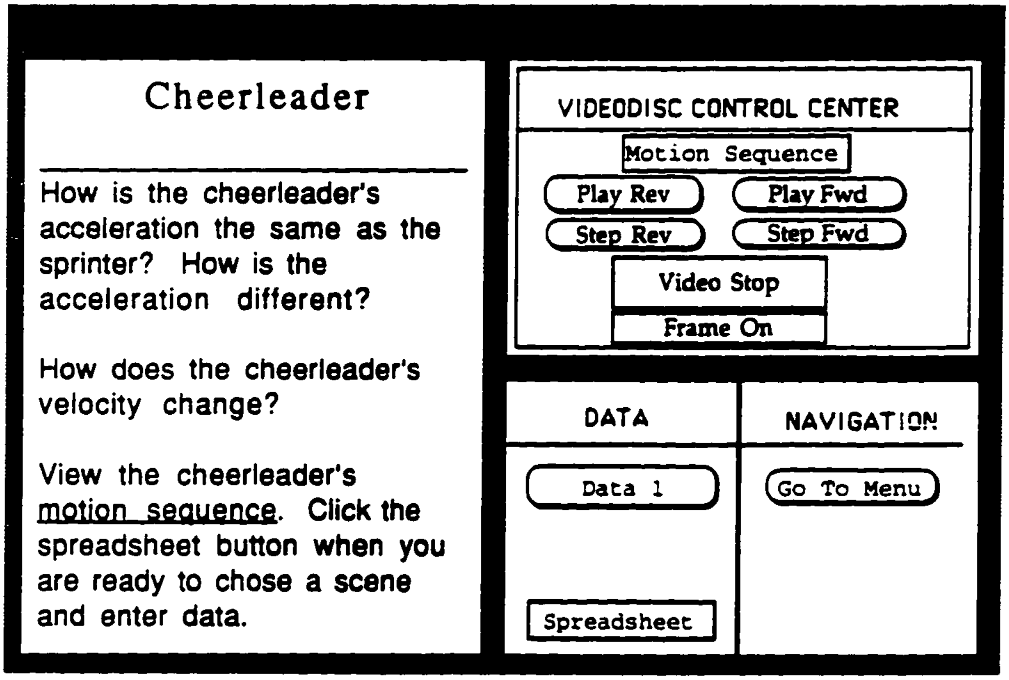


Sprinter

The sprinter begins with a velocity of zero, and accelerates to a great velocity in a short period of time.

Is the acceleration of the sprinter constant?

View the sprinter's motion sequence. Click the spreadsheet button when you are ready to chose a scene and enter data.

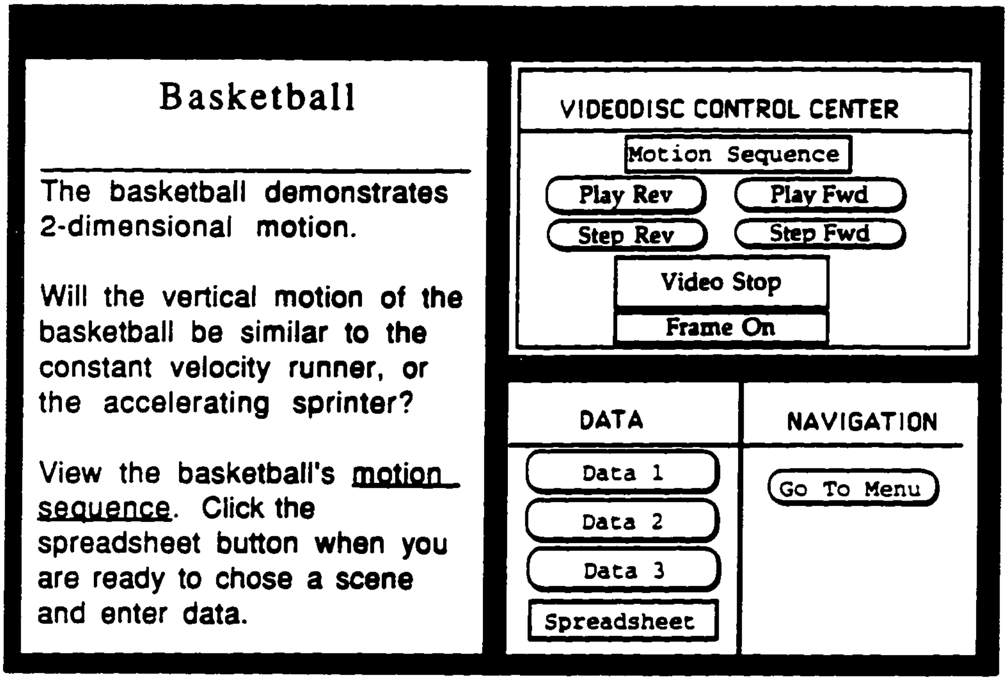


Cheerleader

How is the cheerleader's acceleration the same as the sprinter? How is the acceleration different?

How does the cheerleader's velocity change?

View the cheerleader's motion sequence. Click the spreadsheet button when you are ready to chose a scene and enter data.

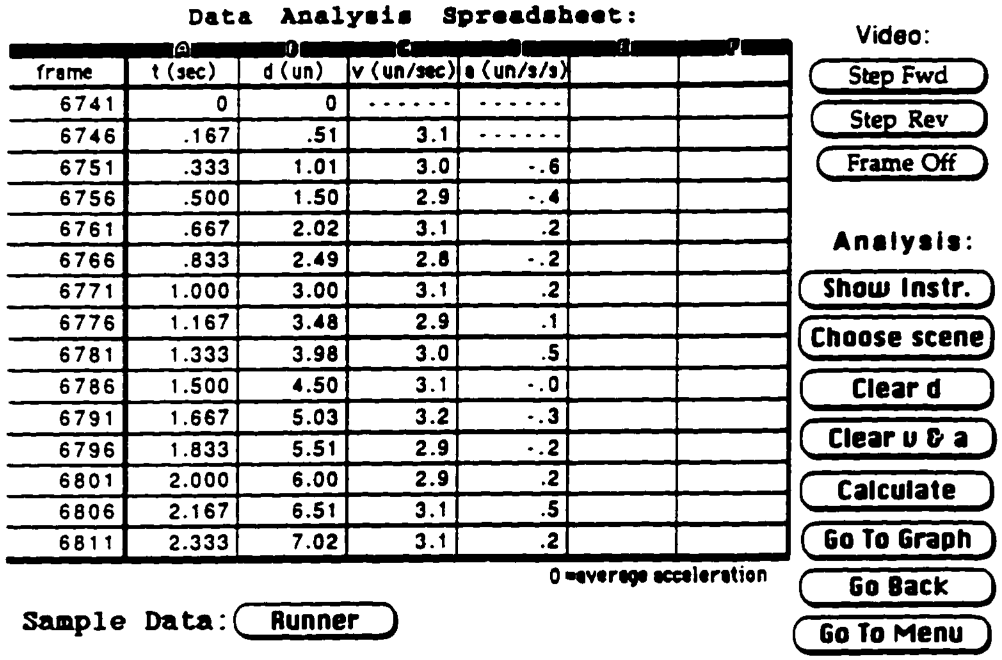


Basketball

The basketball demonstrates 2-dimensional motion.

Will the vertical motion of the basketball be similar to the constant velocity runner, or the accelerating sprinter?

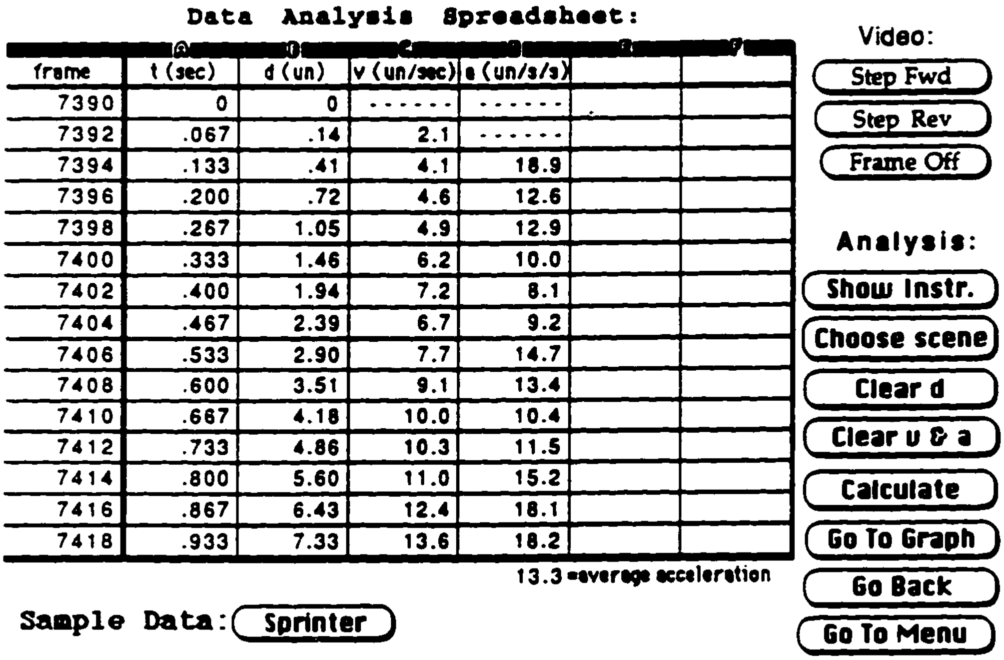
View the basketball's motion sequence. Click the spreadsheet button when you are ready to chose a scene and enter data.



Data Analysis Spreadsheet:

frame	t (sec)	d (un)	v (un/sec)	a (un/s/s)		
6741	0	0	------	------		
6746	.167	.51	3.1	------		
6751	.333	1.01	3.0	-.6		
6756	.500	1.50	2.9	-.4		
6761	.667	2.02	3.1	.2		
6766	.833	2.49	2.8	-.2		
6771	1.000	3.00	3.1	.2		
6776	1.167	3.48	2.9	.1		
6781	1.333	3.98	3.0	.5		
6786	1.500	4.50	3.1	-.0		
6791	1.667	5.03	3.2	-.3		
6796	1.833	5.51	2.9	-.2		
6801	2.000	6.00	2.9	.2		
6806	2.167	6.51	3.1	.5		
6811	2.333	7.02	3.1	.2		

0 =average acceleration

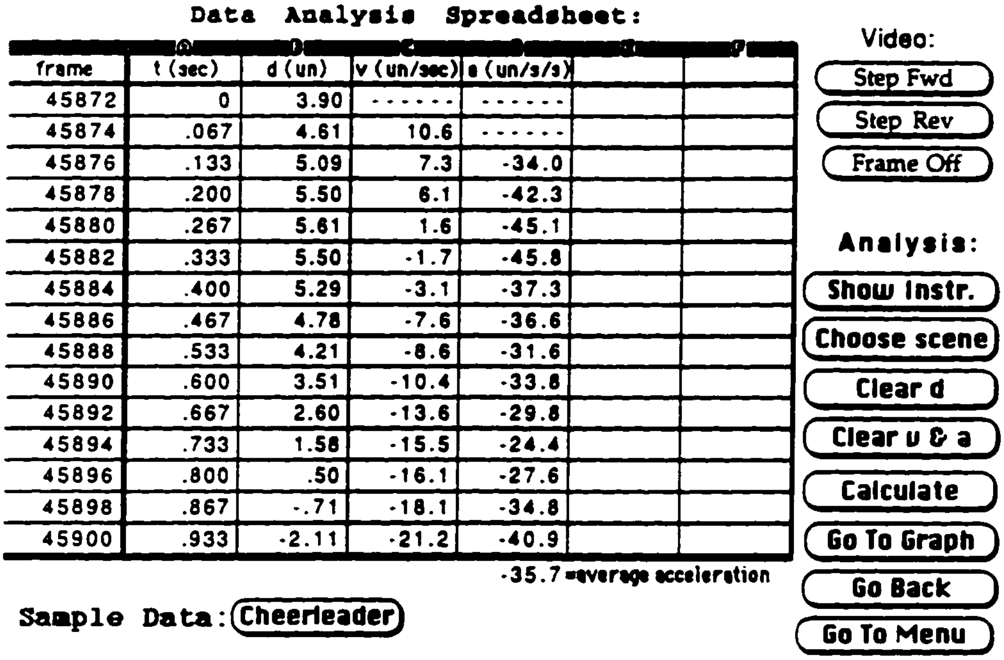


Data Analysis Spreadsheet:

frame	t (sec)	d (un)	v (un/sec)	a (un/s/s)		
7390	0	0	------	------		
7392	.067	.14	2.1	------		
7394	.133	.41	4.1	18.9		
7396	.200	.72	4.6	12.6		
7398	.267	1.05	4.9	12.9		
7400	.333	1.46	6.2	10.0		
7402	.400	1.94	7.2	8.1		
7404	.467	2.39	6.7	9.2		
7406	.533	2.90	7.7	14.7		
7408	.600	3.51	9.1	13.4		
7410	.667	4.18	10.0	10.4		
7412	.733	4.86	10.3	11.5		
7414	.800	5.60	11.0	15.2		
7416	.867	6.43	12.4	18.1		
7418	.933	7.33	13.6	18.2		

13.3 =average acceleration

Sample Data: Sprinter

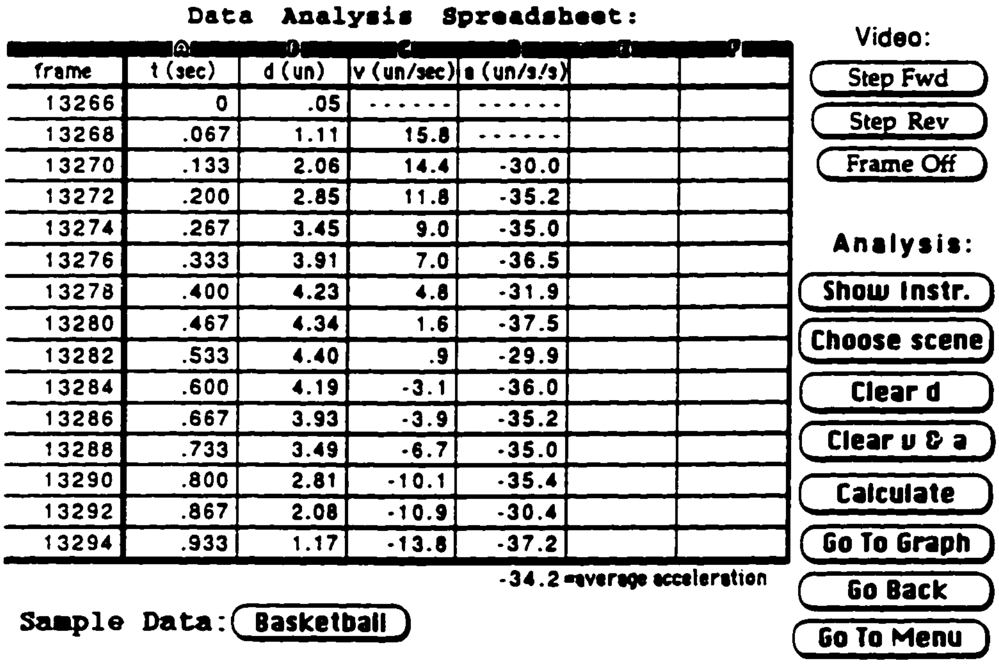


Data Analysis Spreadsheet:

frame	t (sec)	d (un)	v (un/sec)	a (un/s/s)		
45872	0	3.90	------	------		
45874	.067	4.61	10.6	------		
45876	.133	5.09	7.3	-34.0		
45878	.200	5.50	6.1	-42.3		
45880	.267	5.61	1.6	-45.1		
45882	.333	5.50	-1.7	-45.8		
45884	.400	5.29	-3.1	-37.3		
45886	.467	4.78	-7.6	-36.6		
45888	.533	4.21	-8.6	-31.6		
45890	.600	3.51	-10.4	-33.8		
45892	.667	2.60	-13.6	-29.8		
45894	.733	1.58	-15.5	-24.4		
45896	.800	.50	-16.1	-27.6		
45898	.867	-.71	-18.1	-34.8		
45900	.933	-2.11	-21.2	-40.9		

-35.7 =average acceleration

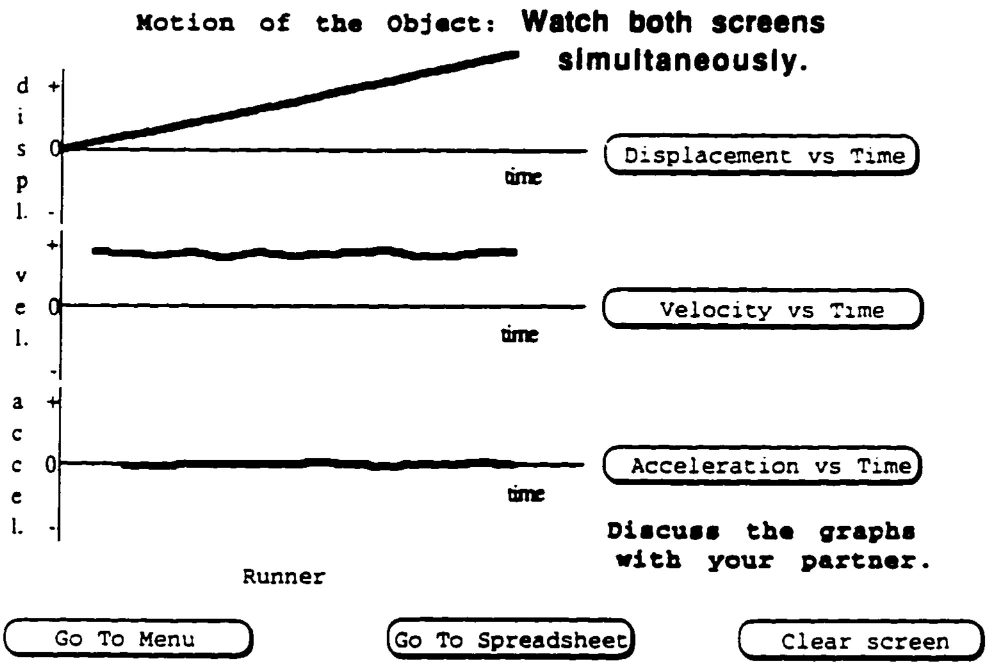
Sample Data: Cheerleader



Data Analysis Spreadsheet:

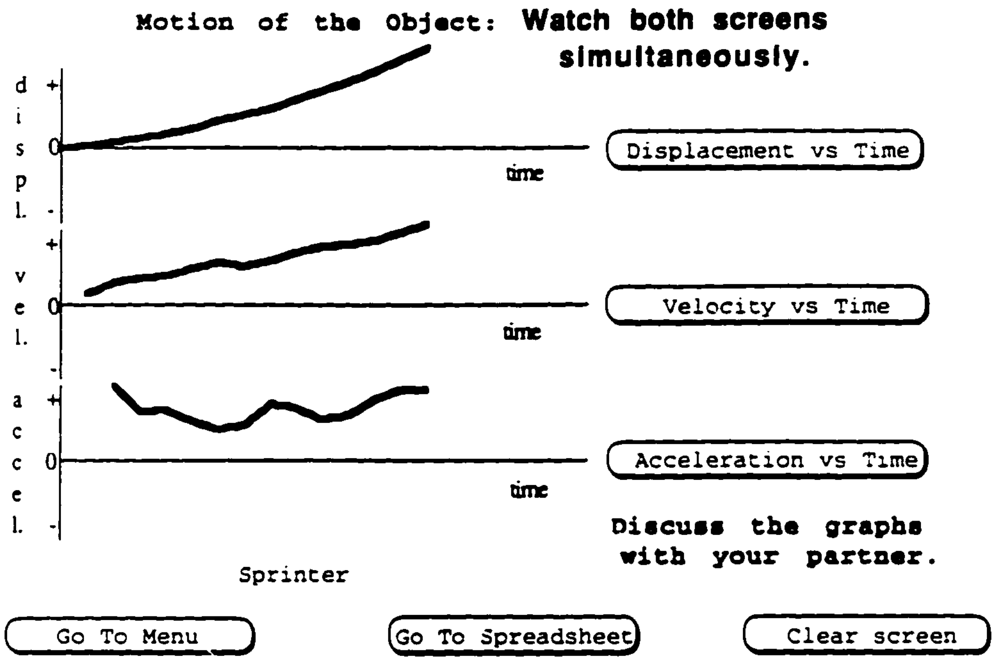
frame	t (sec)	d (un)	v (un/sec)	a (un/s/s)		
13266	0	.05	------	------		
13268	.067	1.11	15.8	------		
13270	.133	2.06	14.4	-30.0		
13272	.200	2.85	11.8	-35.2		
13274	.267	3.45	9.0	-35.0		
13276	.333	3.91	7.0	-36.5		
13278	.400	4.23	4.8	-31.9		
13280	.467	4.34	1.6	-37.5		
13282	.533	4.40	.9	-29.9		
13284	.600	4.19	-3.1	-36.0		
13286	.667	3.93	-3.9	-35.2		
13288	.733	3.49	-6.7	-35.0		
13290	.800	2.81	-10.1	-35.4		
13292	.867	2.08	-10.9	-30.4		
13294	.933	1.17	-13.8	-37.2		

-34.2 =average acceleration



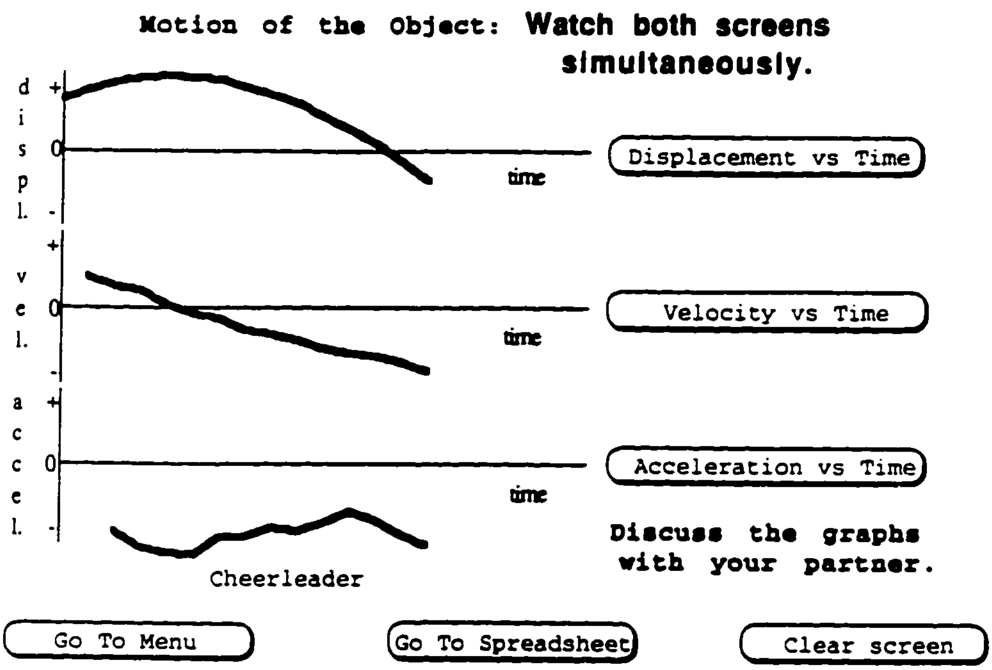
Motion of the Object: **Watch both screens simultaneously.**

Discuss the graphs with your partner.



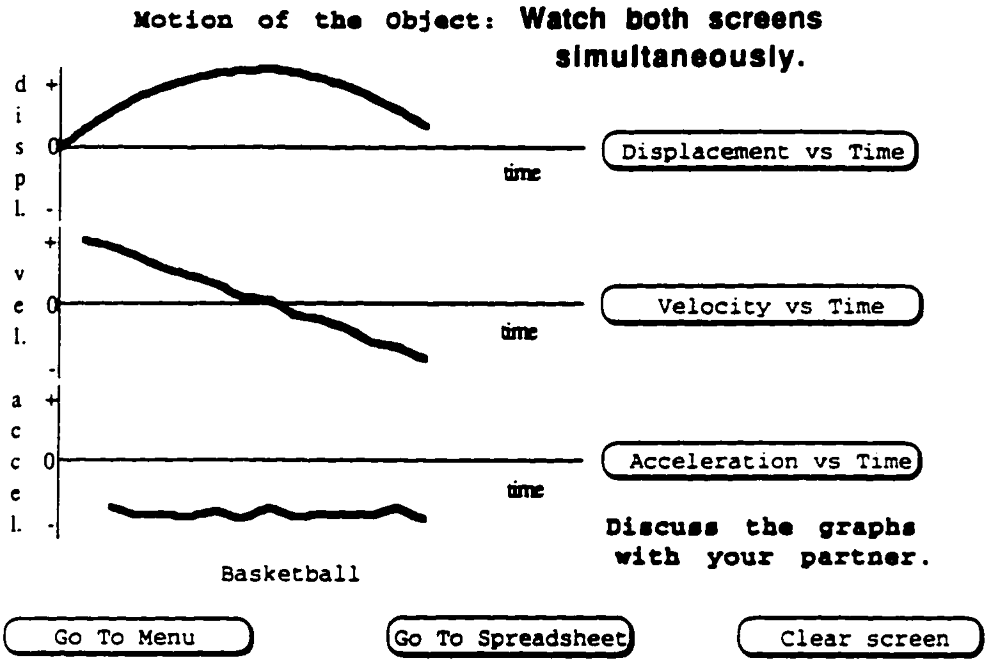
Motion of the Object: **Watch both screens simultaneously.**

Discuss the graphs with your partner.



Motion of the Object: **Watch both screens simultaneously.**

Discuss the graphs with your partner.


Motion of the Object: **Watch both screens simultaneously.**

Discuss the graphs with your partner.

Appendix B—Selected Interviews

Legend of the transcripts of the interviews:
Coding:
    Last digit:
        1 = real-time, and
        2 = delay-time.
    Second-to-last digit:
        1 = first treatment, constant velocity,
        2 = second treatment, 1-D, horizontal, accelerated motion,
        3 = third treatment, 1-D, vertical, accelerated motion,
        4 = fourth treatment, projectile motion, and
        5 = retention interview, projectile motion.
    First one or two digits: student group number.
People involved in transcript:
    I = interviewer, and
    S24 = student number 24.
Parenthetic material refers to this researcher's comments regarding the transcript.
Ellipses (...) refer to pauses, inaudible responses, or incomprehensible responses by the students.
Braces with a number {3} refer to the number of the theme represented by the comment.
Four digit number refers to the VCR counter number.

For example, <511> refers to student group 5, treatment 1, and real-time; <1452> refers to student group 14, retention interview, delay-time.

Selected interview one: real-time group 8, 1-D constant velocity, distance runner:

<811>
1950 Begin
2480 finish instructions
2650 spreadsheet screen
3140 (*software) I still haven't written the script to clear the old displacement entries, so they have to over-type them.

3265 BEGIN GRAPHING.

S16 You're kidding, that is so fresh (*{1} looking at real time effect)! Oh my gosh! That is bad!

S15 Is that the best fit line, or is that the line draw on the dots?

S16 I don't know, that's a good question. That will be steady (referring to the v vs. t graph to be drawn next), it should be steady.

S15 Mr. B., is this a best-fit line, or a line through all the dots?

S16 That's not a best fit line.

I Through all the dots.

S16 That will look a lot like the one above it (predicting a vs. t). Maybe not.

S15 This means, like, negative?

S16 Yeah, remember there were a couple of them negative accelerations on there. (went back to the spreadsheet to verify) See, those are all negative.

S15 What's the difference between velocity and acceleration (*{6} vel./accel. confusion)? Is acceleration how much you accelerated since the last time, and velocity just....

S16 Acceleration is the...I guess...since his average acceleration was 0.7, acceleration with units over seconds squared.... How long it took you to do the first yard is 0.7 less than the last, the second yard...maybe (*{6} vel./accel. confusion).

S16 It was real neat the way it did that (*{1} real-time effect).

S16 That one's so steady (referring to d vs. t).

S16 This one has a lot more jerking motions (v vs. t), velocity does, ...over acceleration. Acceleration is a lot, seems a lot more steady.

3450 END GRAPHING.

3470 BEGIN INTERVIEW.

I Let's go back to the graph. Tell me about the displacement-time graph.

S15 He went at a pretty much gradual...his distance and time relation was pretty much a gradual increase...of the same speed...it didn't go up and down a lot.

I What does that tell you about his motion?

S15 That he was pretty much the same the whole time.

I The same what?

S15 Covered the same amount of distance in the same amount of time (*good)?

I OK, how about the velocity time graph?

S16 Velocity is a lot alike to the displacement vs. time graph, only the displacement shows his distance from the starting point increases as time increases. Velocity shows that his speed, the

amount of distance he was covering as compared to the amount of time he was using was fairly steady...except that there are little peaks and little...these could be due to poor marking or whatever (*good). But it was fairly steady as far as peaks and valleys were concerned.
I OK, how about the acceleration vs. time?
S15 I really don't understand the acceleration...it said units over seconds over seconds again. I guess it's just velocity versus time divided by time again.
I So what was the value of the acceleration?
S16 Nearly zero.
S15 Yeah, pretty much, it was 0.7....
I Nearly zero, what does that mean?
S15 That he had a pretty steady....
I Pretty steady what?
S15 Acceleration (*{6} accel./vel. error, they don't mean constant of zero). He didn't run really fast, then slow down.
3580 END INTERVIEW.

Selected interview two: real-time group 3, 1-D non-zero acceleration, sprinter:

<321>
3980 Begin
S5 Is the acceleration of the sprinter constant (reading from the screen)?
S4 Well, I think once it reached a certain speed, it's constant (*{6} accel./vel. error, they usually don't mean a=0 constant).
S5 That's what we're supposed to find out.
S4 Well I'm just thinking. I'm just making a hypothesis, alright?
4090 didn't view sequence, although directions said to. Should build fool-proof instructions into *software, like "don't go on until instructions are followed."
4170 finally view sequence.
4230 marking acetate
4370 scaling (*software/courseware: gave them numbered graph paper for scaling—this seems to help them decide how to scale).
S5 Did you see that? It computed all the way, then re-computed all those (*software: saw the acceleration curve smoothing routine). It says he slowed down. That was probably when he...each time he stepped (*good). Negative 14.9?

S4 Dang! That's slowing down (*good—this case, OK)! OK, go ahead and show graph.

4651 BEGIN GRAPHING.
S5 It should go up in a linear, nifty line (referring to d vs. t). Acceleration versus time. Here we go! Each time he took a step (*{1} pointing to both screens at once—show this during defense).... Whoa! I don't understand that, I think we did something wrong (*{7} fluctuations). Try that again. Step, slows down, takes a step again, slows down, takes a step again, slows down.... We screwed up somewhere.
S4 That might be right. (to other group) Does that look like a good graph for acceleration?
S5 There's velocity versus time. It should go continuously up, and it doesn't.
S5 Yours is really bad (other groups a vs. t). You guys had a tremendous acceleration.... He wouldn't get a whole bunch of negative accelerations on the last one.... He still accelerates for 20 yards, 10, 20 yards. He's only on 3 yards. He's not even at half speed yet.
S4 I think we have two totally different....
4770 They want to re-do the data. They switch seats, now 5 in foreground, student 4 in background
I Show me the graphs. These are fine.
4990 new scaling data entered.
5090 new graph
S4 Look at that! Nice, even upgrade (d vs. t).
S5 OK, velocity. Each time he pushes off, is when he has acceleration (*good, detailed analysis). Stepping up, it's tremendous acceleration, back down, accelerating again, going down, accelerating again.... I think we screwed up again. I think yours was the best.
S5 I'll show it from my point of view over here, where her cog is. Now you put your point of view, from there. See! Now, look how much we can be off. This is why we were wrong (facing the camera). Cuz, we can be off by that much just by changing our view (*software: good parallax demonstration).
5230 they continue parallax discussion at length.
5250 END GRAPHING.

5250 BEGIN INTERVIEW.
I Tell me about that displacement versus time; why isn't that reasonable (they don't like their data)?
S5 Because he continued to...he displaced farther....

S4 He made less distance in a certain amount of time...er...made more distance in a certain amount of time.

I And, what does that show graphically?

S5 By going up (motions with hand).

I What do you mean, "going up?"

S5 He's going a farther distance...time is on the bottom or the top? In the same amount of time, he has gone a lot farther forward (*good).

I Tell me about the velocity versus time.

S5 Each time he took a step, he slowed down, you can see that (*{1} points to both screens—this student was strongly affected by the real-time approach, also he is very animated in answering). But it went up too, his velocity increased.

I You mean his overall trend?

S5 Yeah. If you drew the best-fit line, it would kind of go up like this.

S4 Yeah, a slight, gradual increase, but you could tell that every time he took a step....

I How about the acceleration?

S4 Possibly, sometimes you slow down, you know, through running, that's what happened. Every time he took a step here, it slowed him down, then he'd take a step again, he'd speed up.

S5 And right here he's at his lowest point, just before acceleration, and I think that might have affected it, with our little error too.

I How about overall, if you were to say an average acceleration, from that graph, what would it be?

S5 Discounting that (points to neg. region)? Oh, it was 5.2 (remembering the spreadsheet—some are more comfortable with a concrete number that a graph that merely depicts pos, neg, or zero).

S4 5.3.

S5 5.3 meters per second acceleration average (*{3} unit error).

I What does that mean?

S5 It means, on average, between here and here, he was accelerating 5.3 feet per second, meters per second. Every second, he would accelerate 5.3 meters more in speed (*{6} vel./accel./displ. error, or is it vocab.?).

I Does the graph make sense, to what the runner was doing?

S5 Other than the acceleration, with this big down.

S4 As we went along, you could tell when he took a step, where the graph would go (*{1} real-time).

5336 END INTERVIEW.

Selected interview three: delay-time group 12, 2-D freefall, cheerleader:

<1232>
125 Begin
S21 Should I measure from the waist?
S24 Sure, why not?
400 marking
480 measuring
S21 If this is zero, this is going to be negative. (cheerleader ended below where she started)
S24 You need to show the first point as zero distance, because you are measuring all points from that point. Cuz, if you measure that one as zero, you're going to have an inverse graph (*{7} error on shape of graph).

890 BEGIN GRAPHING.
S24 That one makes sense (d vs. t).
S24 That one I don't quite understand (v vs. t). Velocity slowed down, as she approaches the top. It sped back up as she went around...to negative, to a negative velocity....
S21 Cuz she's going down (*good).
S24 It would be negative cuz she's going down. (but he has trouble with this concept later in the interview, see below)
S21 Right.
S24 And, it stays constant because roughly....
S21 Because, the pull of gravity (*{9} dynamics).
S24 Acceleration. Goes up and then it (vel.?) would slow, as she goes over, then it would speed back up as she goes back around. Sped up and slows back down...it would tend to even out. Yeah, that makes sense.
S21 Explain that one.
S24 It's measuring the magnitude of her change. Acceleration kind of slowed as she was caught.
1100 END GRAPHING.

1380 BEGIN INTERVIEW.
I Tell me about yours: what about displacement versus time?
S21 Her displacement was negative, then she increased in distance. She was going up, and stopped a certain point, came back down to her original point, and then went past it, like this (acetate).
I So, what does the negative mean?
S21 Negative means that she went past her starting point (*good).
I How about velocity versus time?

S21 Velocity versus time means she increased in velocity, backwards from her starting position, behind her, means negative velocity. She started here, and she's going up, and then she goes from here to the bottom. She goes up, comes back to where she started, then went past it (*{6} displ./vel. confusion—he is correct about neg. displ., but thinks starting point defines when neg. vel. commences) so her velocity was negative. And, the force of gravity is always acting on her when she's in the air.

I Tell me about going up, what's her velocity?

S21 She starts at a certain point, and her velocity is constantly decreased, because of gravity (*{9} dynamics). Gravity is pulling down. At the top she reaches zero, which means she's not moving at all.

I And going down?

S21 She's at a positive number, gravity is acting on her constantly, but, she starts here, and goes backwards, so when she hits zero, she's at the peak, up in the air, and when she goes negative she comes back down.

I How about acceleration, if you were to take an average acceleration?

1515 NOTE: this below is interesting thinking:

S24 That velocity graph is going to be screwed up, because, the displacement shouldn't have been negative. It throws off the displacement graph a bit.

I That should be OK.

S24 When you plug the negative displacement value in the equation, you'd get a negative velocity value. This should be up on top (*{4} dislikes neg. vel. on graph), because she's gaining speed. The graph right there (acetate) shows that she's gaining speed as she goes down.

I Isn't that what the graph shows?

S24 The graph shows that she's losing it (*{4} neg. vel. error). It's negative. Well, I guess it's negative speed. It's....

I What are you thinking? (I think he has found his error)

S24 I guess it works.

I I think you are thinking out loud correctly. Tell me what you are thinking. What about the negative?

S24 The reason you get these spikes....

I Those are errors. Just average that.

S24 Just average this line?

I Right.

S24 The velocity would obviously increase once she reaches the peak. Because we had negative displacement, we don't really know what that peak is. (*{6} neg. displ. error)

I Instead of here, if you would bring it down here (translating the acetate down the graph paper) , would you get the same shape? Would you still get positive velocity, negative velocity?

S21 Yeah.

S24 It seems to say...it's gaining negative velocity as it goes down.

I Think of it in numbers, if you got - 1 m/s, -2 m/s, -3 m/s...isn't that what's happening to her?

S24 Right. She's speeding up, and that's what the acceleration graph shows. When she hits the top, the motion isn't straight up and down, it's more round-about.

1700 END INTERVIEW.

Selected interview four: delay-time group 14, 2-D freefall, basketball:

<1442>

3035 Begin

3220 marking acetate

3340 measuring distance

S30 Do I measure vertical distance from here, going this way?

S26 Yeah. Right.

3547 BEGIN GRAPHING.

S30 (d vs. t) Going up, then going back down.

S30 (v vs. t) Why's it almost straight down? Wouldn't velocity be getting faster as it goes back down? (*{4} neg. vel. problem).... Oh, because it's negative velocity.... Like last time. (*good recovery)

S30 (a vs. t) Oh, my goodness! Acceleration's more when it starts going down than it is when it's going up (fluctuations).

S26 When it's going up, it's still slowing down. When it's going down, it's going faster in the negative direction. It's decreasing even(ly) until it reaches its peak, then...it decreases a little bit....

3625 END GRAPHING.

3643 BEGIN INTERVIEW.

I Tell me about displacement.

S26 Displacement increases...well, the ball's going up...then it levels out, and increases when it's coming back down. (*{6} displ. decreases as it goes down)

I How about velocity?

S26 (inaudible)...then it reaches zero, then it starts increasing a little bit more.

S30 It almost stays the same.
I What do you mean, "reaches zero?"
S26 It stops when it reaches the top.
I And then afterwards?
S26 When it begins increasing a little bit....
S30 Decreasing...well, increasing in the negative direction (*{3} it seems a lot of this might be vocabulary: do we call it increasing, referring to speed, or decreasing, referring to being more negative velocity?)
I What do you mean, "in the negative direction?"
S30 Going down.
I How about the acceleration, and ignore the end part?
S26 Stays the same, pretty much.
I And, what value?
S26 Negative.
I Negative, and what does that mean?
S26 It's going down (*{6} accel./vel. problem).
S30 No. Acceleration's always negative.
I So, when the ball's going up, what's the acceleration?
S26,S30 It's negative.
I It's negative. When the ball's going down, what's the acceleration?
S30 Negative.
I How come it's the same in both cases?
S30 Because of gravity? (*{9} gravity)
I What about gravity?
S30 It's pulling the ball towards the ground.
3710 END INTERVIEW.

Selected interview five (retention interview): real-time student 11, 1-D freefall, ball thrown upwards:

<551.8>
2490 Start
3640 Start projectile
S11 As the ball is thrown upward, it's going to start out at a high velocity, and as it reaches...as gravity (*{9} dynamics) starts to pull down on the ball, it's going to start losing...it's going to start losing it's velocity, so it's distance will not be as great...as it was when it started out. And then when gravity stops the ball, then

it will have...it's distance is steady (3695)...and as gravity starts pulling down on the ball then it starts going back down like this.

I And, what time does it come down, does it hit?

S11 Since gravity affects...since gravity force is a constant, then the same amount of time it took for the ball to be stopped is the same amount it's going to take for it to come back down.

I OK, so it will be what time?

S11 It's going to be about six seconds.

I OK. And let's go ahead to the velocity.

S11 As the ball reaches its highest point, and gravity affects it then its velocity is going to become zero. When the person starts to throw it it's going to start with a high velocity, and as gravity affects it at a constant rate , then the velocity is going to drop to the zero point, then as gravity continues to affect it, it has an increasing velocity in the negative direction. (*good)

I What do you mean, increase in the negative direction?

S11 As you throw up the ball, your...it's going...the distance is in the positive direction, and the velocity is positive, as gravity starts pulling down on the ball, it's forcing it against the positive toward the negative direction as it falls, so velocity is negative (*good).

I And what did you say happened at the three second point?

S11 The ball stopped, then velocity was zero.

I And let's try acceleration.

S11 Since the velocity is constant, then there is...there is...(long pause)

I You remember from the videodisc, the basketball example? (long pause) Tell me what you're thinking about.

S11 Well, as the ball is thrown upward, gravity starts to affect it, the ball's going to be decellerating, or accelerating in the negative direction. As it reaches its highest point, then the velocity is zero. So it no longer is accelerating (*{5} accel. error, a=0 at top), or in either direction, and then, as gravity starts to affect it again, then it's accelerating in the negative direction.

I So you said both going upward and going downward it was accelerating in the negative direction. How can you draw that graphically?

S11 Since its velocity is decreasing constantly, then its acceleration in the negative direction must be constant also.

I OK, how do you draw that?

S11 It would be a straight line, and then, as it reaches zero, (wants to get accel. to zero) there is no acceleration, or de-accelleration, as the ball is just, at the top of its point (*{7} discontinuous graph—jumps up to zero at peak) . And then, it's accelerating at a constant rate, er, its velocity is a constant rate in the negative direction, so its acceleration must be constant also. (can't seem to internally justify it, but he insists that a must to to 0 at top)

I So is it going to be constant in positive or constant in negative?

S11 Gravity pulling down on it in the negative direction is going to be negative.

I So how do you draw that on the graph?

S11 It's going to be constant again, so its going to be a straight line... Like that (*{5} draws it correctly, but still has the discontinuity at t=3s).

I Tell me again about what happens at the top, at its peak.

S11 At its peak, it's no longer accelerating in a positive or negative direction, the ball, has a zero velocity, it is just sitting there. And so, it must have an acceleration of zero (*{5} accel. error—v=0 implies a=0 error)

I And what's the cause of the acceleration?

S11 It's gravity (*{9} dynamics). It's pulling down on the ball.

I And what happens to gravity when the ball's at its peak?

S11 It's still affecting it.

I OK, how would you show that graphically?

S11 Well, as, gravity would be affecting it constantly, so it's going to have a constant negative acceleration (*good—draws the correct graph). So it's going to be a straight line like this.

I OK. But it seemed to you at the beginning that zero velocity must mean zero acceleration. Correct?

S11 Yeah.

I But you're thinking now that, ...does it still seem like a contradiction?

S11 No, I guess, an object can be forced upon and still have a negative acceleration and slow down to zero.

I Because what happens right after zero?

S11 It continues at the same rate.

I So, could you say that the object was changing its velocity...at the top?

S11 No (*{5} still accel. misconception).

I Could you say it was changing from positive to negative?

S11 Yeah.

I And that would be a change in velocity, wouldn't it? So that would be a change in acceleration (interviewer error here).

4195 END.