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THE EFFECT OF DATA ACQUISITION-PROBEWARE AND DIGITAL VIDEO ANALYSIS ON ACCURATE GRAPHICAL REPRESENTATION OF KINETICS IN A HIGH SCHOOL PHYSICS CLASS

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By

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ABSTRACT

THE EFFECT OF DATA ACQUISITION-PROBEWARE AND DIGITAL VIDEO ANALYSIS ON ACCURATE GRAPHICAL REPRESENTATION OF KINETICS IN A HIGH SCHOOL PHYSICS CLASS

By

William B. Struck

The effects of two types of microcomputer-based methods on the ability of high school physics students to accurately graph kinetics using distance, velocity and acceleration versus time graphs were studied. Student graphing skills were evaluated before, during and after they used data acquisition-probeware (DAP) and digital video analysis (DVA) to investigate a variety of one-dimensional motions. Half of the students, placed in random groups, first investigated these motions with DAP and later with DVA. The other half of the students investigated the same motions with the same equipment but in the reverse order. Both these strategies were found to be successful and complementary. There were indications student achievement was higher for velocity-time and acceleration-time graphs using the DVA method.

I dedicate this thesis to the memory of my late parents, Herman and Dorothy Struck. Without their unwavering love, profound belief in the value of education and boundless support in countless ways, this work would never have come to pass.

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INTRODUCTION

As far back as 1957 when the Soviet Union launched Sputnik, the American public, its leaders and educators have become increasing concerned over how our science and math students compare to those from other countries. At that time, the Cold War was in full swing and the threat was military in nature and national pride was at stake. More recently the concern has focused on whether or not our students are equipped to compete in an increasingly global job market. Studies such as National Assessment of Educational Progress (NAEP) and Third in International Mathematics and Science Study (TIMSS) are examples of the growing evidence of the shortcomings of United States students relative to students from other industrialized nations around the world.

The thirty year NAEP study recognized a high interested in "back to the basics" in reading, mathematics and science. This study found that reading scores for our 17-year-olds are not significantly different from 1971 to 1999. Mathematics scores for 17-year-olds do show a significant, though slight (1.3%), increase from 1973 to 1999. However in science the picture is less encouraging: the overall scores of 17- year-olds declined from 1969 to 1982, increased modestly from 1982 to 1992 and have since leveled off. The end-of-the-study levels (1999) in science for 17-year-olds were significantly below (3.4%) the beginning-of-the-study levels (1969) (Campbell, J.R., Hombo, C.M., and Mazzeo, J., 2000).

The Third in International Mathematics and Science Study (TIMSS) has studied and still is studying global trends in math and science education achievement and curriculum. Its focus is on two groups: 4th and 8th graders. In the 1999 report on science, 8th grade US students rank significantly below fourteen (14) countries, are statistically even with five (5) and significantly higher than eighteen (18) countries. This "middle of the pack" picture is not a proud one for our leaders, educators, employers and ordinary citizens who are concerned with how US students are equipped to compete for employment opportunities in an increasingly global market (National Center for Education Statistics).

Recently, additional influence on the direction of science education comes from No Child Left Behind Act of 2001. The goal of this legislation is to improve the performance of our primary and secondary schools through more rigorous standards of accountability—often called standards-based educational reform. The underlying principle is that setting lofty goals will improve the performance of all students. One key component to this legislation is to improve teacher quality by insisting that teachers are "highly qualified." The measure for this focuses on minimally achieving a bachelor's degree, teaching only in areas of their major or minor or passing rigorous academic state tests. Finally, testing achievement is required in science for elementary, middle school and high school science students.

Some believe that the high percentage of foreign students in the graduate programs at American universities limits future opportunities for American high school students entering college. A survey by the National Science Foundation counted the number of foreign students (as defined as temporary visa holders) and the number of US citizens and permanent residents for "first-time, graduate enrollment." For the period of 2000-2004, in the physical sciences the percentage of foreign students entering graduate programs ranged from 39% to 45%. For the same period, in the mathematical sciences the percentage of foreign students entering graduate programs ranged from 38% to 46%.

(National Science Foundation, 2006). This high percentage of foreign students in US graduate programs relative to US citizens further emphasizes the rigor of the challenge that US students face from foreign countries.

The Call for Reform

This study was designed to improve science education by searching for more effective ways of teaching graphing skills related to a high school kinetics unit. Though achievement is everyone's goal in science education, reform continually focuses on curriculum standards, funding, policies and billions of dollars just for assessment. All of these seem to drive instruction.

For example The National Research Council compiled a list of data-related competencies that students should achieve. A portion of this are:

- Describe and represent relationships with tables, graphs, and rules.
- Construct, read, and interpret tables, charts, and graphs.
- Analyze tables and graphs to identify properties and relationships (NRC, 1996, p.121).

This study was implemented to compare the effectiveness of two different computer-based technologies in an attempt to improve the ability of high school physics students to inter-relate various one-dimensional motion situations with distance-time, velocity-time and acceleration-time graphs. Half the students in a high school physics classes used data acquisition probeware (DAP) and then later used digital video analysis (DVA) to examine one-dimensional motions. The other half of the students in the same classes used identical equipment to study the same motions but did so in the reverse order. All students were asked to complete distance-time (d-t), velocity-time (v-t) and acceleration-time (a-t) graphs for these motions before starting, after using just one method of study and a third time after using both methods of study. Observing students during this unit on one-dimensional kinetics unit in a high school offered physics course provided an excellent opportunity to compare the relative effects of both DAP and DVA on student kinetic graphing skills.

Traditional educational methods such as teachers lecturing and students dutifully listening ("I teach; you learn") have been shown to be seriously lacking. The mid-twentieth century work of Jean Piaget identified four distinct stages of cognitive learning: sensory-motor, preoperational, concrete operational and, by about age 11, the formal operational stage (Berg & Phillips, 1994). It is no longer accepted that students simply receive knowledge. Beginning with Piaget our understanding of science learning and teaching has deepened considerably. Over the past 40 years the work of Lev Vygotsky and others has seen constructivism become the theoretical basis that educators use to make sense of science instruction. Constructivism holds that the background and level of achievement of each learner is the starting point. It then defines a "zone of proximal development" which encompasses skills and concepts that the child is capable of doing with adult guidance. Within that framework, children develop new skills and revise their concepts to accommodate new discoveries (Lemke, 2001). In the constructivism theory, instructors are viewed as facilitators rather than as deliverers of knowledge—teachers (Furman & Barton, 2006). The learning process is an active social process that calls for collaboration between the instructor, the learner and the learner's peers (Kozma & Russell, 1997; Gijlers & Jong, 2005). Marcia Linn, who worked with Piaget, is responsible for the "Scaffolded Knowledge Integration framework" (SKI). Linn holds that there are four components to science learning. First is the introduction of various models and creation of an environment that encourages the investigation of these models. The second component of SKI is what Linn calls "making thinking visible." This is essentially the clear encouragement of debating various models. The third component of SKI is the need to convey to students that this debate is never-ending and is something true scientists do throughout their lives. The fourth and final component is providing the classroom environment that encourages productive social interaction. Linn's SKI evolved into a related framework called "Knowledge Integration Environment" (KIE). A KIE brings together "technical, cognitive, and social resources to create a productive electronic learning community." (Bell, P., Davis, E. A., & Linn, M. C., 1995) From Liu, Saed Sabah (2007) summarizes Linn's key points for designing effective science instruction:

1. "...link new ideas to what students already know."
2. "Teachers and technology can help illustrate the complexity of scientific thinking and introduce arguments."
3. "Foster the social interaction in order to let students learn from each other."
4. "Creating lifelong learners. In other words, 'students need opportunities for sustained project work...'"

Creation of just such an environment was one of the goals of this study. Small groups of students brought together different theories about what kinetics graphs should look like. They were supplied with various technologies (probes, computers, video cameras and software) to study the one-dimensional motions and put into a small group environment designed to provide the time and a relaxed atmosphere conducive to peer learning.

However, remarkably few specific teaching strategies to improve student outcomes in science have been proposed and without well-grounded strategies, teachers may be ill equipped to help their students reach the stated goals (Bowen & Roth, 2005). To make progress in this theater, direct classroom research aligned to specific skills is needed to investigate the impact particular activities have on achievement. It was the aim of this study to make just such a contribution by studying specific technology and related activities and examine their relationship to student actions.

Computers for educational purposes first became available in the 1970's and various educational applications have evolved. One of the most enduring uses of computers is their use for practice, drill and simulations (Adams & Shrum, 1990). Microcomputer-based laboratories (MBL) were first seen in the early 1980's and are attractive for a variety of reasons: data acquisition that is quicker, more accurate and in some cases impossible without MBL (Eisele, 1982). They lend themselves well to the effective sequence for studying science suggested by Russell, Lucas and McRobbie (2004): predicting, setting up, observing, analyzing and explaining. Kinetic motion is especially amenable to study via MBL. By using a sonic motion detector linked to a microcomputer students can collect and store data for very short time intervals, very quickly and very accurately. These data can then be displayed in real time as a distance versus time (d-t), velocity versus time (v-t) or acceleration versus time (a-t) graphs. The ease and accuracy of gathering the data and generating graphs help make student-lead investigations more efficient and meaningful (Graef, 1983).

Misconception research has been a major contribution to our understanding of the constructivist nature of learning. Lillian McDermott believed that students "often have similar conceptual and learning difficulties" and understanding these difficulties will prove helpful in designing effective physics instruction. For example, in kinetics/graphing studies students sometimes mistakenly generate graphs as a "picture" of the event (Linn, M., Layman, J., & Nachmias, R., 1987). A ball rolling down a hill is an example of positive acceleration but students often draw a velocity vs time graph of this event with negative slope (deceleration) to look like the hill (Beichner, 1990). This confusion with velocity-time graphs has been described by Brungardt & Zollman (1995) as students' difficulty "with the vector nature of physical quantities." This "graphs as pictures" phenomenon was also observed by others (Mokros & Tinker, 1987). Acceleration versus time graphs present similar and perhaps even stronger challenges because students "have a hard time distinguishing between a quantity [height on a graph] and a change of that quantity" (Lockhead, 1980).

Students learning to interpret graphs has been a topic of concern. Graphical presentations are a common form of communication in science, engineering and math (Mokros & Tinker, 1987). Articles in scientific journals frequently use graphs to report and discuss their results. While high school textbooks have about as many images (non-text) as scientific journals, textbooks have far fewer graphs and those they do have lack rigorous scaling (Bowen, Roth & McGinn, 1999).

Using graphs to study kinetics in a high school physics course provides a good opportunity for students to construct their own knowledge, have some of their misconceptions challenged and practice, in a hands-on way, to construct various kinds of graphs (Mokros & Tinker, 1987). The cognitive development of most students taking high school physics (16-18 years old) lends itself to the abstract representations that graphs offer. These students have moved from the concrete operational stage to the formal operational stage and the others are at least in the process of making that transition (Mokros, 1986).

One-dimensional kinetics is often one of the first topics taught in a high school physics course. A simple example would be one object moving at a constant velocity. Higher complexity would be one object starting from different relative positions, still moving at a constant velocity but in different directions and different velocities. Later higher complexity motion is studied—one with steadily changing velocity (constant non-zero acceleration). At each of these levels the complexity can be increased by using more than one object. Unless the high school physics course is calculus-based, this is as complex as it gets. Two-dimensional kinetics is studied as a combination of constant velocity and constant acceleration motion with one object (projectiles). The study of collisions, both elastic and inelastic, is an extension of constant velocity two-object motion with of course the addition of the factors of mass and momentum.

In this study two different methods of data acquisition and study were compared. Specifically, the effectiveness of real-time graphical methods using data acquisition probeware (DAP) was compared to the effectiveness of another method with a significant time delay between the motion/data acquisition and the production of graphs using digital video analysis (DVA). There are conflicting reports about the impacts of such delays. Brasell (1987) reported that a delay between the motion and appearance of a graph of just 20 seconds had a negative impact on learning while others found no such impact (Beichner, 1990 and Brungardt & Zollman, 1995). A higher level of interest and less confusion between v-t and a-t graphs has been reported for groups using real-time graphing techniques like DAP as opposed to delay-time groups like DVA (Escalada and Zollman, 1997). Both methods were controlled by the students and had students performing the actual motions, providing important "kinesthetic feedback" (Beichner, 1990).

Study Site

Williamston, Michigan is a town 15 miles east of the Lansing and has a population of about 3,500 people. Formerly a rural farming community, Williamston has become more of a residential town with farming still in the surrounding areas. The largest employer in the city is Williamston Community Schools (170 employees). Many of its residents commute to work in nearby Lansing, East Lansing and Okemos (Census profiles). The town is well known for its numerous antique shops. The community prides itself in maintaining its small, cohesive, friendly town atmosphere. This theme is reflected in the town motto: "Discover the Charm."

The Williamston Community Schools has four schools: Discovery (K-2), Explorer (3-5), Middle School (6-8) and High School (9-12). Williamston High School has a yearly enrollment of approximately 675 students. Williamston schools are not racially diverse: they are 93.4% white, 1.2% African-American, 3.0% Hispanic, 2.1%

Asian/Pacific Islander and 0.3% Native-Americans. The average family income in Williamston is $51,000. Only 7.0% of the students are classified as economically disadvantaged compared to 35.2% for the State of Michigan as a whole (School Matters).

Students who take physics at Williamston High School are required to first take Biology and Physical Science and at least Advanced Algebra. Most have also completed Chemistry and either Functions, Statistics and Trigonometry (FST) or Pre-Calculus. Most students taking physics have a strong interest in science and many go on to major in a science in college. The majority of the physics students are relatively strong academically—it's unusual for the valedictorians not to have taken physics. Some students are capable of being successful in physics but don't keep pace with the rigorous homework and lab demands. Each year a few students enroll against the advice of their counselor and/or previous science teachers. Due to weak math skills and weak study habits, a significant percentage of these drop the course by the end of the 1st semester. Thirty-nine of the 44 enrolled students completed the study (89%). The five students who did not complete the study were absent during a significant number of activities and got out of the test/activity sequence. This kinetics unit was early in the first semester so no students had yet dropped the course. By the end of the year, 5 students had dropped the class—11% of the original enrollment. So it is reasonable to say that the students who completed this study represent a typical group of Williamston students taking physics in the early fall.

IMPLEMENTATION

In this study, students used two methods to investigate one object moving in 1 dimension and two objects moving in 1 dimension. One method required sonic motion detectors linked to the PASCO Xplorer GLX hand-held computers. This method was called digital acquisition probeware (DAP). The second method was called digital video analysis (DVA). It required a low resolution digital video camera (Canon), LoggerPro 3.0 software from Vernier and desktop computers belonging to the students or in the school's computer labs. These methods were chosen for the study because both use technology now readily available for high school physics classes.

Prior to beginning their investigation, students were given a test (T1) to evaluate their initial abilities at graphing motion. (See appendices 1 and 2.) During this test they were given eleven (11) motion circumstances and asked to sketch three graphs for each: 1) distance vs time, 2) velocity vs time and 3) acceleration vs time. For each motion situation, students were also asked to rate the complexity of the problem using a 1-5 scale. One week later students were randomly placed in groups of three to study the eleven motion situations. Half the groups had sonic motion detectors linked to hand-held graphing computers (DAP) while the other groups took digital movies and created graphs on personal computers using digital video analysis software (DVA). Two days later students were then retested (T2) on the same set of eleven motion situations. Two days later groups switched equipment to reexamine the same motion situations. Three days later students took the evaluation test for a third and final time (T3). The total duration of the study was 15 days. This sequence is summarized on the following flow chart entitled "Implementation Scheme."

Implementation Scheme

Three tests were taken (T1, T2 and T3)

Each test described eleven motion circumstances.

For each motion, students were asked to sketch three graphs: distance-time, velocity-time and acceleration-time (see appendix 1).

For each motion, students were also asked to rate how they perceived the complexity of the motion circumstance: least complex to most complex on a 1-5 scale.

Between tests, students examined the eleven motion situations using two methods:

Digital acquisition probeware (DAP) from PASCO

Digital video analysis (DVA) from Vernier

Group 1 (DVA followed by DAP)

T1 → seven days → DVA → two days → T2 → two days → DAP → three days → T3

Group 2 (DAP followed by DVA)

T1 → seven days → DAP → two days → T2 → two days → DVA → three days → T3

The interaction of students during these exercises was observed and the pre, mid and post graphing sketches (T1, T2, and T3, respectively) were scored using a common rubric. Results were evaluated graphically and statistically.

Each sonic motion detectors was linked to a hand-held computer. With data acquisition-probeware (DAP) that allowed real-time data capture and graphical display. PASCO sonic detectors are sensitive in a 15-800 cm range and have sampling rates of 0.020 seconds. Students were instructed to use themselves as the moving object. Since sonic motion detectors cannot distinguish between different objects, multiple object circumstances were studied one object at a time. During each motion, by using the computer's keyboard and display, students were able to immediately view plots of distance-time, velocity-time and acceleration-time. DAP allows students to construct their own experiment, be directly involved kinesthetically and see real-time d-t, v-t and a-t graphs of motion events.

The digital video analysis method (DVA) required two steps. First a low resolution digital video was taken of each motion and the data were captured on a 3 1/2" floppy disk. Once again students used themselves as the moving object. Because of the low resolution and brevity of each movie (usually 5 seconds or less), the file size was small and easily conveyed to each member of the group by email or by copying the file to a floppy disk. Each student subsequently used LoggerPro 3.0 (Vernier) to analyze the filmed motion and eventually developed distance-time, velocity-time and acceleration-time graphs for each motion. This process required a PC. When each video file was opened with LoggerPro two scaling tasks were required: 1) an origin (known as "homebase") was established with two mouse clicks and 2) a distance scale was established by clicking and dragging on a meter stick that was visible in each video. With those preliminary steps out of the way then the motion was digitally traced by placing the cursor on the object. A click of the mouse recorded the position of the object and advanced the movie by one frame—equivalent to $1/30^{th}$ of a second. Once the video analysis was completed, distance-time, velocity-time and acceleration-time graphs were easily viewed on the computer screen and/or printed out. Best-fit lines were also easily generated and viewed. The shape and slope of these best-fit lines on a distance-time graph helped students view the magnitude and sign of velocity. Similarly, the shape and slope of these best-fit lines on a velocity-time graph helped students comprehend the magnitude and sign of acceleration. DVA does not produce real-time graphs but does require students to construct the activity, actually perform the motion, analyze the video data and finally view the graphical results.

These two methods of motion evaluation had some commonalities and several distinct differences. Both methods required close group cooperation during the data collection. Instructions were read together and students had to agree on what the instructions meant. Then group members divided up the jobs: one or more members would perform the motion while another recorded data by starting the sonic motion/computer or taking the digital movie. Whether or not the captured data were within acceptable limits could easily and quickly be determined by both methods of study. The DAP had a screen that gave a real-time graphical display of the event and the DVA allowed for an immediate review of the captured movie. Groups would frequently repeat a motion until "clean" data were captured for study.

Using the DAP method, motion graphs were studied immediately through the on screen display features. Distance vs time data were the default mode of display. Some modest-level computer skills were required to bring up the velocity vs time and acceleration vs time displays. Typically, at least one group member quickly figured out how to do that and either taught the other group members or simply performed the necessary key strokes after each motion and showed his group members the three different graphs. Most groups started the sonic detector and data collection before the motion. This created a brief "acceleration spike" as the moving person went from motionless to some constant non-zero speed. Students quickly accepted these spikes as "start-up anomalies." Multi-object motions had to be studied with separate runs. Motion was always relative to the detector: motion could be going either away from the detector (giving a positive slope on a distance vs time graph) or toward the detector (giving a negative slope on a distance vs time graph). Distances from the detector would always be displayed as positive (above the x-axis).

The DVA method differed somewhat from the DAP. Though the initial video required group cooperation, the analysis of each video take was done separately by each individual, at a later time and usually outside of the classroom. The DVA method required more time overall: slightly less classroom time but considerably much more time outside the classroom and in front of a computer. The analysis was considerably delayed from the initial time of the filming. However, the motion studied could be reviewed as many times as desired simply by replaying the video. Multiple object motions were filmed simultaneously and their respective motion graphs could be also be viewed simultaneously. Since the origin (homebase) could be set anywhere on the screen, both positive as well as negative distances could be graphed.

Once students sketched graphical representations of the various motion situations, their sketches were scored and averages were calculated. These average scores of actual student performance were themselves graphed as part of the analysis for this project. These result graphs were then compared to graphs of several hypothetical educational outcomes. The hypothetical outcome graphs took into account two factors:

1) the pre-study skill level of each group

2) the amount of improvement after each method of study.

Pre-study skill levels of each group (groups "A" and "B") had three possibilities: A = B, A > B, and A < B. The amount of improvement after each method of study ("C" and "D") also had three possibilities: C = D, C > D and C < D. This lead to the construction of five hypothetical graphs (appendices 5 to 9):

Hypothetical #1	Pre-study skill level: A = B
	Amount of improvement: C = D
Hypothetical #2	Pre-study skill level: $A \neq B$
	Amount of improvement: C = D
Hypothetical #3	Pre-study skill level: A = B
	Amount of improvement: C > D
Hypothetical #4	Pre-study skill level: A < B
	Amount of improvement: C > D
Hypothetical #5	Pre-study skill level: A > B
	Amount of improvement: C > D

Results

Eleven motion situations were studied. Thirty-nine students each sketched a d-t, v-t and a-t graph for these eleven situations at three different times: T1, T2 and T3. In all, 3,861 graphs were sketched by students. These student-generated graphs were blindly scored, recorded and statistically compared. The statistical evaluation of graph score changes was made using the General Linear Model and a P value of ≤ 0.05 for 95% reliability. Improvement trends from pre-investigation levels to mid-investigation levels (T1 to T2), from mid-investigation to ending levels (T2 to T3) and from pre-investigation levels to ending levels (T1 to T3) were examined for all graphs (d-t, v-t and a-t) and for a composite score (the sum of d-t, v-t and a-t scores). A Pearson Correlation Coefficient ($P \leq 0.05$) was generated to relate students' perception of each motion's complexity to their composite score for each of the eleven motion circumstances. These results are summarized in appendix G. Any differences between the two methods of learning (DAP and DVA) were also evaluated. Beginning scores (T1), mid-point scores (T2) and final scores (T3) were statistically compared. These results are summarized in Tables 1-4. The scores were also graphed and compared to hypothetical graphing patterns (appendices 5-9).

Table 1

T1 to T2, % changes

	A	B	C	D	E	F	G	H	I	J	K
d-t			+9.8	+21	+12%	+9.2	+16			+19	+19
v-t		**+9.7**	+22	+23	+25				+26	+55	+54
a-t								+13		+18	+27
composite			+11	+17	+12		+13	+9.3	+14	+28	+31

- Each column, A-K, represents one the eleven motions studied (appendix 1).
- The first three rows contain the improvement of the average scores for the distance-time, velocity-time and acceleration-time sketches from the initial test (T1) to the mid-study test (T2).
- The bottom row contains the improvement of the average of the total scores for all three is the sketches for the same time period.
- All posted results were statistically significant (General Linear Model, $P \leq 0.05$).
- Blank boxes indicate that there was no significant change.
- **Bold** indicates that group 1 was statistically stronger than group 2.

Table 2

T2 to T3, % changes

	A	B	C	D	E	F	G	H	I	J	K
d-t											
v-t						+16				+16	+15
a-t		**+9.7**	**+8.8**	+11		+9.0			**+11**	+9.3	
composite		+4.0	+4.8	+7.0	+5.2	+7.8	+7.0	+6.1	+6.4	+7.8	**+8.1**

- Each column, A-K, represents one the eleven motions studied (appendix 1).
- The first three rows contain the improvement of the average scores for the distance-time, velocity-time and acceleration-time sketches from the mid-study test (T2) to the final test (T3).
- The bottom row contains the improvement of the average of the total scores for all three is the sketches for the same time period.
- All posted results were statistically significant (General Linear Model, $P \leq 0.05$).
- Blank boxes indicate that there was no significant change.
- **Bold** indicates that group 1 was statistically stronger than group 2.

Table 3

T1 to T3, % changes

	A	B	C	D	E	F	G	H	I	J	K
d-t			+11	+22	+13	+9.2	+18			+19	+20
v-t		**+12**	+28	+36	+34	+27	+36	+27	+38	+80	+78
a-t		+13	+12	+19	+11	+11	+12	+22	+25	+29	+39
composite		+8.5	+16	+25	+18	+16	+21	+16	+22	+37	+42

- Each column, A-K, represents one the eleven motions studied (appendix 1).
- The first three rows contain the improvement of the average scores for the distance-time, velocity-time and acceleration-time sketches from the initial test (T1) to the final test (T3).
- The bottom row contains the improvement of the average of the total scores for all three is the sketches for the same time period.
- All posted results were statistically significant (General Linear Model, $P \leq 0.05$).
- Blank boxes indicate that there was no significant change.
- **Bold** indicates that group 1 was statistically stronger than group 2.

Table 4

Complexity Ratings

	A	B	C	D	E	F	G	H	I	J	K
T1	1.3	2.1	2.3	**2.7**	2.7	2.8	2.8	3.1	3.0	3.4	3.9
T2	1.1	1.6	1.6	2.0	**2.1**	**2.1**	**2.2**	2.6	**2.6**	**3.0**	**3.4**
T3	1.1	1.4	**1.6**	**1.8**	**2.0**	**2.0**	**2.0**	**2.5**	**2.5**	**2.7**	**2.9**

- Each column, A-K, represents one the eleven motions studied (appendix 1).
- The three rows contain the average of the complexity scores that students gave for each motion during the initial test (T1), mid-study test (T2) and the final test (T3).
- The scale was from 1 (least complex) to 5 (most complex).
- **Bold** indicates a positive correlation between the complexity score with composite score (Pearson Correlation Coefficient , $P \leq 0.05$).

Motion A: An object starts at homebase, is initially motionless and remains motionless.

This was the simplest motion circumstance—no motion. Students had very high competency scores on all three graphs on all three tests (T1, T2 and T3)--in the 95-100% range. They also rated this scenario as the least complex of the 11 motion circumstances: 1.3 (on a 1-5 scale) at T1 and 1.1 at T3. No significant improvement was measured for any graph for either group at any stage.

Motion B: An object starts at homebase and moves steadily to the right.

During the T1 testing, students scored very high on their distance vs time graphs (98%) but less well on their graphs of velocity vs time (81%) and acceleration vs time (83%). The most common error was a v-t graph with a positive slope starting from the origin rather than a horizontal zero-slope line above the x-axis. No improvement in d-t graphs was found at any stage. Velocity-time graphs improved to ~90% from T1 to T2. Group 1, the group first using digit video analysis (DVA), showed significantly higher gains than group 2, the group first using digital acquisition probeware (DAP). No additional improvement was found in v-t graphs from T2 to T3. Acceleration-time graphs showed no improvement until T2 to T3 and group 1 again showed higher gains. Distance-time graphs scores were 98.3% at T1 and 100% at T3--no significant overall improvement. Overall improvement (from T1 to T3) was found for both v-t and a-t graphs with group 1 showing stronger gains in the v-t graph but no group differences were seen in the a-t graphs. The complexity of the circumstance was 2.0 at T1 and steadily decreased to 1.4 by T-3. No correlation was found between student complexity perceptions and composite scores.

Motion C: An object starts at homebase and moves steadily to the left.

This motion was identical to the previous circumstance in starting place, number of objects and constant velocity. The only difference was the direction of movement: to the left of homebase instead of to the right. Distance-time graphs at T1 were lower than previous scores (81%) and rose by 9.8% from T1 to T2 but not significantly after that. Velocity-time graphs improved even more dramatically (22%) from T1 to T2 but again not from T2 to T3. Acceleration-time graphs did not improve from T1 to T2 but rose by 12% from T2 to T3 with Group 2, using DVA, showing significantly higher gains. Overall improvement was measured for all three time periods for all three graphs with no group differences. Complexity perception scores diminished from 2.3 at T1 to 1.6 at T2 and T3. There was a positive correlation between students' complexity perception and there composite score at T3.

Motion D: An object starts to the right of homebase and moves steadily to the left.

This is the first of the motions to be analyzed that does not start at homebase. However the motion brings it closer to or even past homebase. Both groups of students recognized this motion as more complex and challenging than the first three. The d-t scores at T1 were the lowest average yet: 81%. This was primarily due to the misplacement of the object's beginning position. From T1 to T2, dramatic improvement of d-t graphs (21%) and v-t graphs (23%) was shown; however, neither d-t nor v-t graphs improved from T2 to T3. Acceleration-time graphs improved (11%) from T2 to T3. All three graphs show significant overall improvement (T1 to T3). No group differences were seen in any graph at any stage. The level of student confidence improved from a T1 score of 2.7 to a T3 score of 1.8. Positive correlations between this complexity perception and composite scores at T1 and T3 were found.

Motion E: An object starts to the left of homebase and moves steadily to the right.

This motion is a mirror image of the previous motion so one might expect similar scores and trends. Interestingly, the confidence level was not as high as the previous motion but the performance was nearly identical. Significant improvement of d-t graphs (up 12% to 98%) and v-t graphs (up 23% to 80%) was shown during T1 to T2. No significant difference in d-t and v-t graphs was seen from T2 to T3. No improvement was seen for a-t graphs from either T1 to T2 or T2 to T3. Overall improvement was seen in all three graphs. No group differences were seen in any graph at any stage. The level of student confidence improved from a T1 score of 2.7 to a T3 score of 2.0. Positive correlations between complexity perception and composite scores at T2 and T3 were found.

Motion F: An object starts to the right of homebase and moves steadily to the right.

This motion is unidirectional: the object starts and moves right. Perhaps because of the similarity with the previous motion circumstances, students showed improvement of d-t graphs from T1 to T2 only: from 89% to 97%. Velocity-time graphs improved from T2 to T3 but not from T1 to T2. Similarly, acceleration-time graphs improved from T2 to T3 but not from T1 to T2. Overall improvement was seen in all three graphs. No group differences were seen in any graph at any stage. The level of student confidence improved from a T1 score of 2.8 to a T3 score of 2.0. Positive correlations between complexity perception and composite scores at T2 and T3 were again found.

Motion G: An object starts to the left of homebase and moves steadily to the left.

Like the previous motion, this was unidirectional: the object starts and moves left. Students showed improvement of d-t graphs from T1 to T2 only: from 82% to 95%. Students showed no significant improvement in their v-t graphs from either T1 to T2 or T2 to T3. Students also showed no significant improvement in their a-t graphs from either T1 to T2 or T2 to T3. Overall improvement was seen in all three graphs. No group differences were seen in any graph at any stage. The level of student confidence improved from a T1 score of 2.8 to a T3 score of 2.0. Positive correlations between complexity perception and composite scores at T2 and T3 were once again found.

Motion H: Two objects start at homebase and both move steadily to the right. The black object moves faster than the blue object.

This is first time students had been introduced to 2-object motion and different velocities. The objects were moving in the same direction, at different but constant speeds. These two new variables pushed student complexity perception ratings to their highest levels (3.1). Distance-time graphs started high (96%) and finished even higher (99%) and showed no significant improvement during either T1 to T2 or T2 to T3. Velocity-time graphs also showed modest upward trends (71% to 82% to 90%) but were not significant for either T1 to T2 or T2 to T3. Acceleration-time graphs showed improvement from T1 to T2 but not during T2 to T3. Overall improvement was seen in v-t and a-t graphs but not in d-t graphs. No group differences were seen in any graph at any stage. The level of student confidence improved from a T1 score of 3.1 to a T3 score of 2.5. A positive correlation between complexity perception and composite scores at T3 was found.

Motion I: Two objects start at homebase and both move steadily and at the same speed. The blue object moves to the left and the black object moves to the right.

This motion differed from the previous one (Motion H) because the objects move in different directions at the same speed. Students perceived this as the same complexity level as Motion H. Distance-time graphs once again started high (92%) and finished even higher (99%) and showed no significant improvement during either T1 to T2 or T2 to T3. Velocity-time graphs improved markedly (26%) from T1 to T2 but not from T2 to T3. Acceleration-time graphs did not improve from T1 to T2 but rose by 11% from T2 to T3 with Group 2, using DVA, showing significantly higher gains. Overall improvement was again seen in v-t and a-t graphs but not in d-t graphs. No group differences were seen in any graph at any stage except for the a-t graphs from T2 to T3. The level of student confidence improved from a T1 score of 3.0 to a T3 score of 2.5. Positive correlations between complexity perception and composite scores at T2 and T3 were once again found.

Motion J: Two objects start in the same position to the right homebase. Both objects move steadily toward homebase—the black object moves faster than the blue object.

This motion has the same starting position and directions of movement but different speeds. Students showed gains with all graphs at all times except with d-t graphs from T2 to T3. The highest overall gains were shown in v-t graphs (80%) compared to a-t graphs (29%) and d-t graphs (19%). No group differences were seen in any graph at any stage. The level of student confidence improved from a T1 score of 3.4

to 3.0 at T2 to 2.7 at T3. Positive correlations between complexity perception and composite scores at T2 and T3 were once again found.

Motion K: A black object starts 1.0 m to the left of homebase and the blue object starts 2.0 m to the right. Both move steadily toward homebase. The blue is the first to arrive at homebase.

This motion was the most challenging of all for students to analyze. Both objects started away from homebase, one to the left and one to the right and at different distances. Both objects moved in different directions at different speeds. Not surprisingly students rated this motion complexity higher than any other at both the beginning (3.9) and at the end (2.9). Students made strong gains in all their graphs from T1 to T2: 19% in d-t graphs, 54% in v-t graphs and 27% in a-t graphs. From T2 to T3, students continued to show improvement for v-t graphs (15%) but no additional in their d-t and a-t graphs. Overall improvement was seen in all three graphs. No group differences were seen in any graph at any stage. The level of student confidence improved from 3.9 at T1 to 3.4 at T2 to 2.9 at T3. Positive correlations between complexity perception and composite scores at T2 and T3 were once again found.

DISCUSSION

The combined use of digital video analysis (DVA) and data acquisition probeware (DAP) by high school physics students consistently produced significant overall improvement in their graphing skills. In a few cases, after studying motion using DVA, students made more improvement producing v-t and a-t graphs than after using DAP. Based on self-ratings, for all eleven motion situations studied and at every stage of investigation (after using either DVA and DAP) students became increasingly comfortable with their motion graphing skills.

Overall improvement of student skills for graphical representation of motion situations isn't surprising after the activities used for this study. Students spent over a week studying the relationship between these motions and how they should be represented on d-t, v-t and a-t graphs. Students also constructed their own experiment and kinesthetically experienced the motions and either immediately saw those motions graphed (DAP) or created their own graphs by gleaning position and time measurement from digital videos using video digital analysis software. During each motion, by using the computer's keyboard and display, students were able to immediately view plots of distance-time, velocity-time and acceleration-time. Several researchers have reported that the combination of these factors gives the best cognitive results (Brasell, 1987; Mokros & Tinker, 1987; Beichner, 1990). These activities had students personally involved in actual motion events and some other researchers have reported that viewing a realistic event may be a more important factor for student learning than the real-time factor (Brungardt and Zollman, 1995). Since students took videos of their own motion, these events when viewed later on a computer certainly qualify as realistic.

Distance-time graphing skills increased to high levels independent of which method of study was used by students. No improvement was seen only when high levels (>90%) had already been achieved. In several cases (motions A, B, H and I) these high levels were already present before the unit began (T1). In all other cases (C, D, E, F, G, J and K), high levels d-t graphing skills were quickly achieved (by T2) regardless of method of study (DVA or DAP).

However, students' velocity-time graph scores were consistently lower than their scores for d-t graphs. This isn't surprising since some students see graphs as pictures (Linn, M., Layman, J., & Nachmias, R., 1987). A d-t graph comes the closest to a picture. Further up or down the y-axis (distance) is further away. Above the horizontal axis represents one direction while below it represents the opposite direction. But v-t represents a rate of movement and an a-t graph represents a rate of change of movement. Both are a long way from being pictures (Brungardt & Zollman, 1995). Velocity-time and a-t graphs require students to reason beyond the concrete stage--the formal operational stage.

In this study, this progression of difficulty was seen. As mentioned earlier, d-t graphs were drawn with a high degree of skill with one level of study with either method or, in a third of the cases, with no study at all. Velocity-time graphing skills began at a lower level, progressed significantly using just one study method (by T2) in 70% of the cases. Unlike d-t graphing skills, v-t graphing skills continued to improve in some cases (30%) through the use of the second method of study. Overall improvement of v-t graphing skills was seen in all but the simplest, already well-understood, circumstance. Improvement ranged from 12% in a simple case (B) to about 80% in the most complex cases (J & K). One case (B) indicated that perhaps DVA was a more powerful method but it's difficult to explain how seeing this effect in only 1 out of 10 situations signifies a trend.

Acceleration-time graphs once again showed how one more level of complexity challenged students. Both initial and final scores in student a-t graphs were lower than their v-t scores. And improvement was harder to achieve despite the ample room "at the top." In only 30% of the cases (ignoring A—the motionless situation) was improvement demonstrated after using just one method (H, J and K). Sixty percent of the motion situations (B, C, D, F, I and J) showed improvement after using a second method of study (T2 to T3). Overall improvement for v-t and a-t graphs was seen for all 10 motion situations but average a-t gains were modest (19%) when compared to average gains for v-t graphs (40%). This modest improvement in a-t graphing skills may be due to several factors: 1) an a-t graph is one more level away from concrete thinking therefore a tougher concept for many students (Lockhead, 1980), 2) observing an a-t graph using DAP requires more key strokes than d-t and v-t graphs and 3) generating an a-t graph using DVA likewise requires more data manipulation before it can be viewed. Any combination of these challenges makes drawing correct a-t graphs a more daunting task. There were three cases in T2 to T3 where DVA may have lead to higher scores. But it should be noted that these students had used DVA after using DAP. If DVA were a big advantage to understanding a-t graphs, one might expect to see these differences in students using DVA before using DAP. But this was not the case.

The correlation between high complexity perception scores and high composite scores is interesting. This may show that students less skilled with the more challenging v-t and a-t graphs are not even aware of the challenges. Conversely those students who are more aware of how challenging v-t and a-t graphs are, especially for the more complex motions (D-K), were better prepared to correctly sketch them.

It may be that the use of both DVA and DAP is beneficial and complementary. Having both methods available is probably a luxury few high schools can afford. At one level, the time delay between the actual motion and appearance of a graph (when using DVA) did not seem to affect overall student learning. However, there may be at least a second level to consider. The potential damaging effect of this delay, if there is one, could be offset or more than offset by two advantages of DVA: a) the opportunity that it affords students the opportunity to repeatedly "relive" the motion by replaying the video and 2) simply spending more time on task—analyzing the videos took a significant amount of out-of-class time. Conflicting reports about the effect of time delay have been previously reported (Brasell, 1987; Beichner, 1990 and Brungardt & Zollman, 1995). Most students and some teachers would see this extra time required by DVA as a negative. Indeed, due to time constraints, the plan for students to study and graph more complex motion circumstances (e.g. constant but non-zero acceleration) was abandoned (appendices 3 and 4).

Future Research

With more time it would be interesting to study results using the more complex motion scenarios (appendices 3 and 4). These are more challenging situations because they describe constant non-zero acceleration situations, motions of multiple objects at unequal speeds and have stop-start motions. Research comparing the effectiveness of DVA and DAP for these situations would be interesting. The ability of DVA to simultaneously analyze multiple objects and later present them on a single graph might show stronger student gains in those types of circumstances.

Doing a similar study with a larger population (this study involved only 39 students) might produce more significant results. In this study, graphs of some of the results showed patterns similar to hypothetical graphs for unequal method effects but these effects were not statistically significant.

It would also be interesting to study motions of objects that were not students to see if their physical participation would make a significant difference. It would be relatively easy to use basketballs or motion carts for non-human motion. Both DAP and DVA adapt easily to those objects. A study comparing a group using human motion to a group using non-human motion might be able to measure whether or not direct student involvement makes a difference in the improvement of their graphing skills.

Longer and higher resolution videos that produce larger files are now more practical due to widespread use of jump drives. Students can now easily transport very large files home or to school computer labs and study them with digital video analysis software without having to send them through a high speed internet connection. This makes the use of DVA easier and applicable to more complex motions requiring longer duration videos. Higher resolution digital movies make the study of small objects motion (golf balls and air pucks are examples) more easily accomplished using DVA. Sonic motion detectors (used in DAP) may not be sensitive enough for such studies. The effect of object size on student improvement would be an interesting topic for future research.

APPENDICES

Appendix 1

Motion Evaluation I

Conventions & Reminders:

1) The origin represents "homebase."

2) When observed from a spot perpendicular to the original direction of motion, positions to the right of homebase are considered positive.

3) For each motion described below, carefully sketch three graphs:
   - distance vs time
   - velocity vs time
   - acceleration vs time

4) For each motion rate how difficult it was for you to sketch the appropriate graphs. One (1) is for "very easy" and five (5) is for "very difficult."

Motions:

A) An object starts at homebase, is initially motionless and remains motionless.

B) An object starts at homebase and moves steadily to the right.

C) An object starts at homebase and moves steadily to the left.

D) An object starts to the right of homebase and moves steadily to the left.

E) An object starts to the lef t of homebase and moves steadily to the right.

F) An object starts to the right of homebase and moves steadily to the right.

G) An object starts to the left of homebase and moves steadily to the left.

H) Two objects start at homebase and both move steadily to the right. The black object moves faster than the blue object.

I) Two objects start at homebase and both move steadily and at the same speed. The blue object moves to the left and the black object moves to the right.

J) Two objects start in the same position to the right homebase. Both objects move steadily toward homebase—the black object moves faster than the blue object.

K) A black object starts 1.0 m to the left of homebase and the blue object starts 2.0 m to the right. Both move steadily toward homebase. The blue is the first to arrive at homebase.

Appendix 2

A distance vs time

velocity vs time

acceleration vs time

easy——————hard
1 2 3 4 5

B distance vs time

velocity vs time

acceleration vs time

easy——————hard
1 2 3 4 5

C distance vs time

velocity vs time

acceleration vs time

easy——————hard
1 2 3 4 5

D distance vs time

velocity vs time

acceleration vs time

easy——————hard
1 2 3 4 5

Appendix 3

Motion Evaluation II

Conventions & Reminders:

1) The origin represents "homebase."

2) When observed from a spot perpendicular to the original direction of motion, positions to the right of homebase are considered positive.

3) For each motion described below, carefully sketch three graphs:
    - distance vs time
    - velocity vs time
    - acceleration vs time

4) For each motion rate how difficult it was for you to sketch the appropriate graphs. One (1) is for "very easy" and five (5) is for "very difficult."

Motions:

A) An object starts at homebase, is initially motionless and experiences constant positive acceleration.

B) An object starts at homebase, is initially motionless and experiences constant negative acceleration.

C) An object starts to the right of homebase, is initially motionless and experiences constant negative acceleration.

D) An object starts to the left of homebase, is initially motionless and experiences constant positive acceleration.

E) An object starts to the right of homebase, is initially moving to the right experiences constant negative acceleration.

F) An object starts to the left of homebase, is initially moving to the left and experiences constant positive acceleration.

G) Two objects start at homebase, both are initially motionless and both experience constant positive acceleration. The red object's acceleration is greater than the green object's.

H) A red object starts to the right of homebase while the green object starts at homebase. Both are initially motionless and both object experience the same negative constant acceleration.

I) Two objects start at homebase. Both are initially moving to the right—the green object's initial motion is faster than the red object's. Both experience identical constant negative acceleration.

J) A green object is to the right of homebase a red object is twice as far to the left of homebase. The green object experiences negative acceleration and the red object experiences positive acceleration. The magnitude of the red object's acceleration is triple that of the green object.

Appendix 4

Motion Evaluation III

Conventions & Reminders:

1) The origin represents "homebase."

2) When observed from a spot perpendicular to the original direction of motion, positions to the right of homebase are considered positive.

3) For each motion described below, carefully sketch three graphs:
   - distance vs time
   - velocity vs time
   - acceleration vs time

4) For each motion rate how difficult it was for you to sketch the appropriate graphs. One (1) is for "very easy" and five (5) is for "very difficult."

Motions:

A) An object starts at homebase, slowly and steadily moves to the right, stops for second and then moves quickly and steadily to the right.

B) An object starts at homebase, and steadily moves to the left, stops for 2 seconds and then moves steadily to the right. The speed of the left movement is equal to the speed of the right movement.

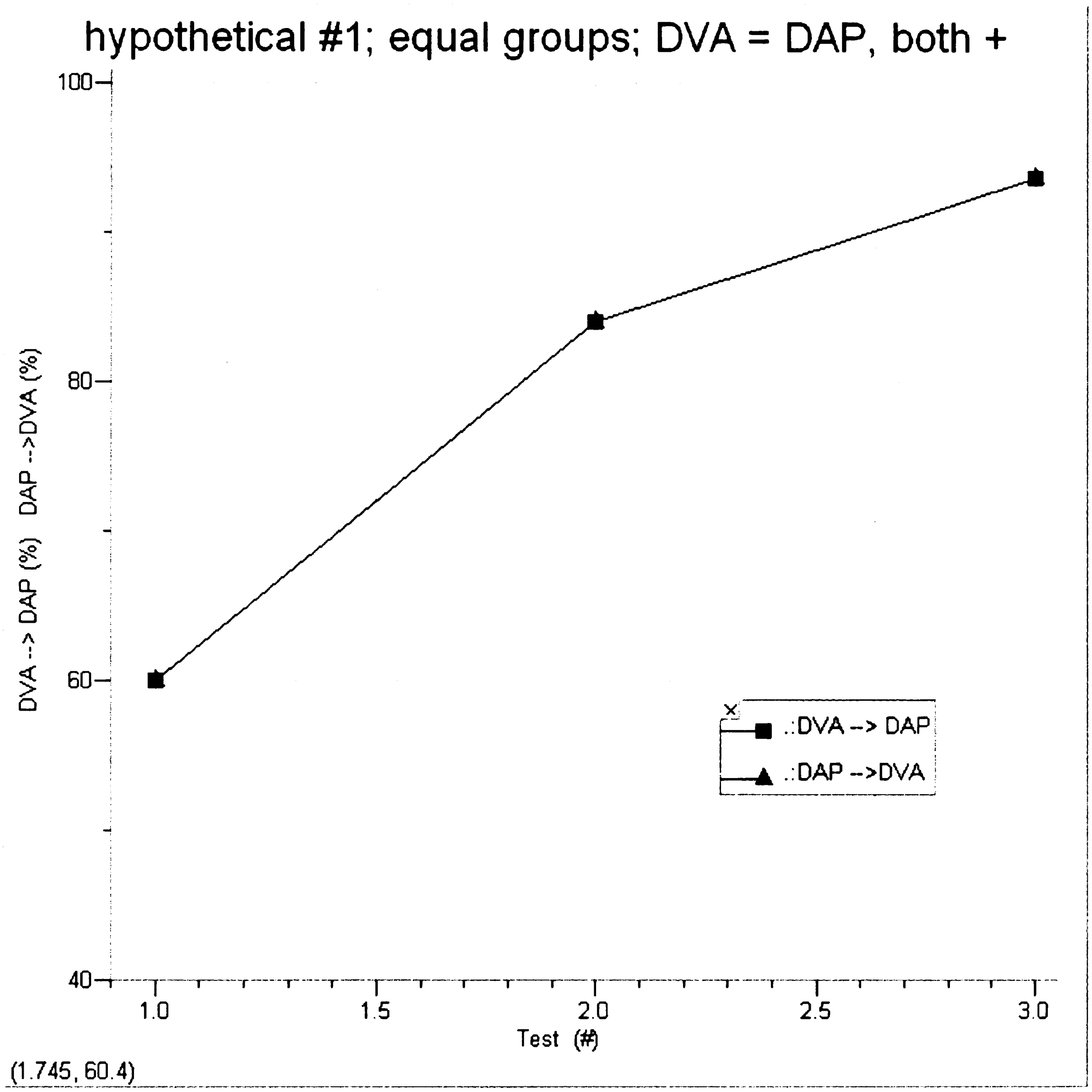
C) An object starts to the left of homebase, slowly and steadily moves to the left and then immediately moves quickly and steadily to the right.

D) An object starts to the left of homebase, moves steadily to the right, stops for 1 second and then accelerates steadily to the left.

E) An object starts to the right of homebase, is initially moving to the left and accelerates steadily to the right.

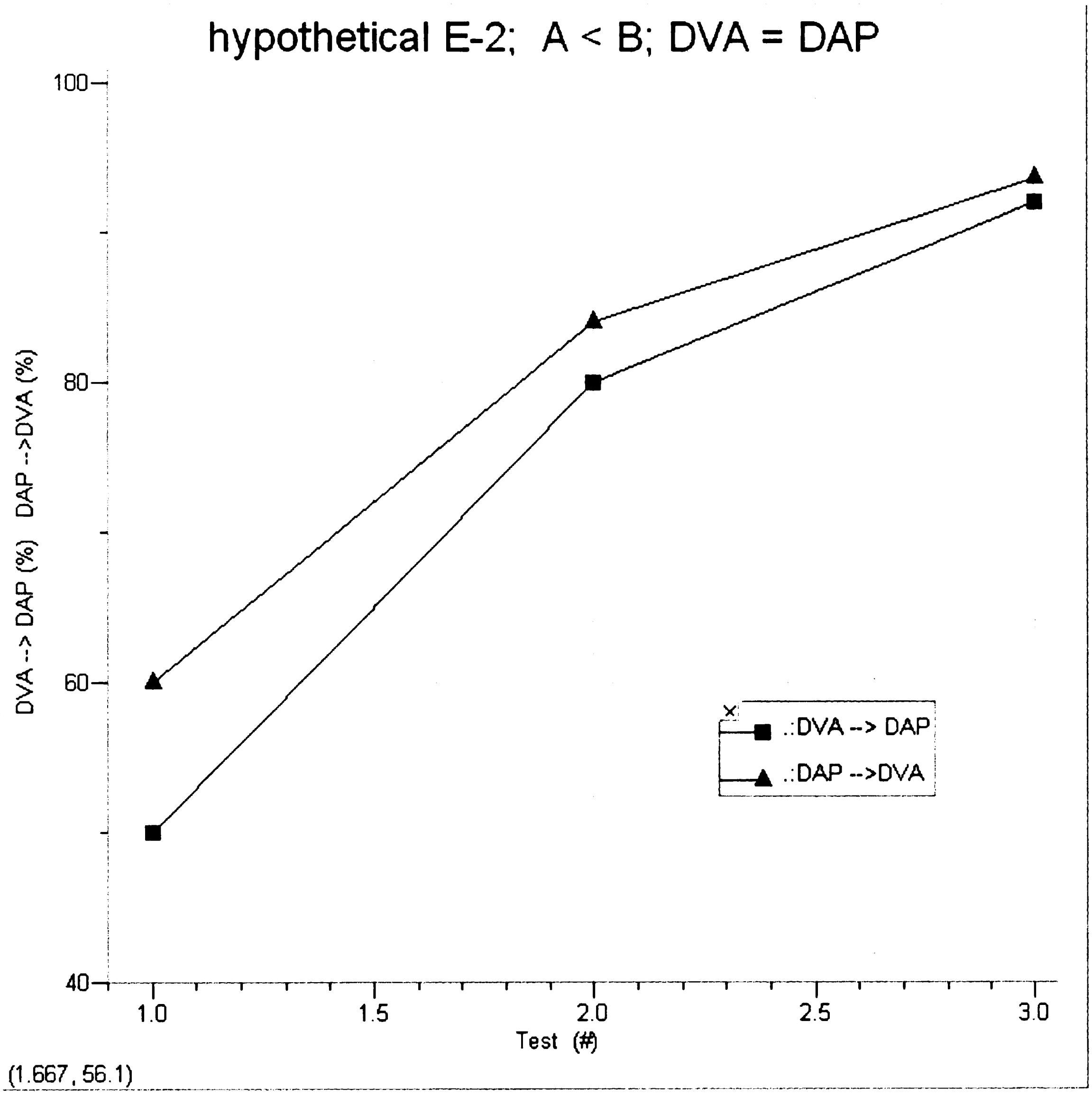
F) An object starts to the left of homebase, steadily accelerates to the right and then moves steadily to the right.

Appendix 5



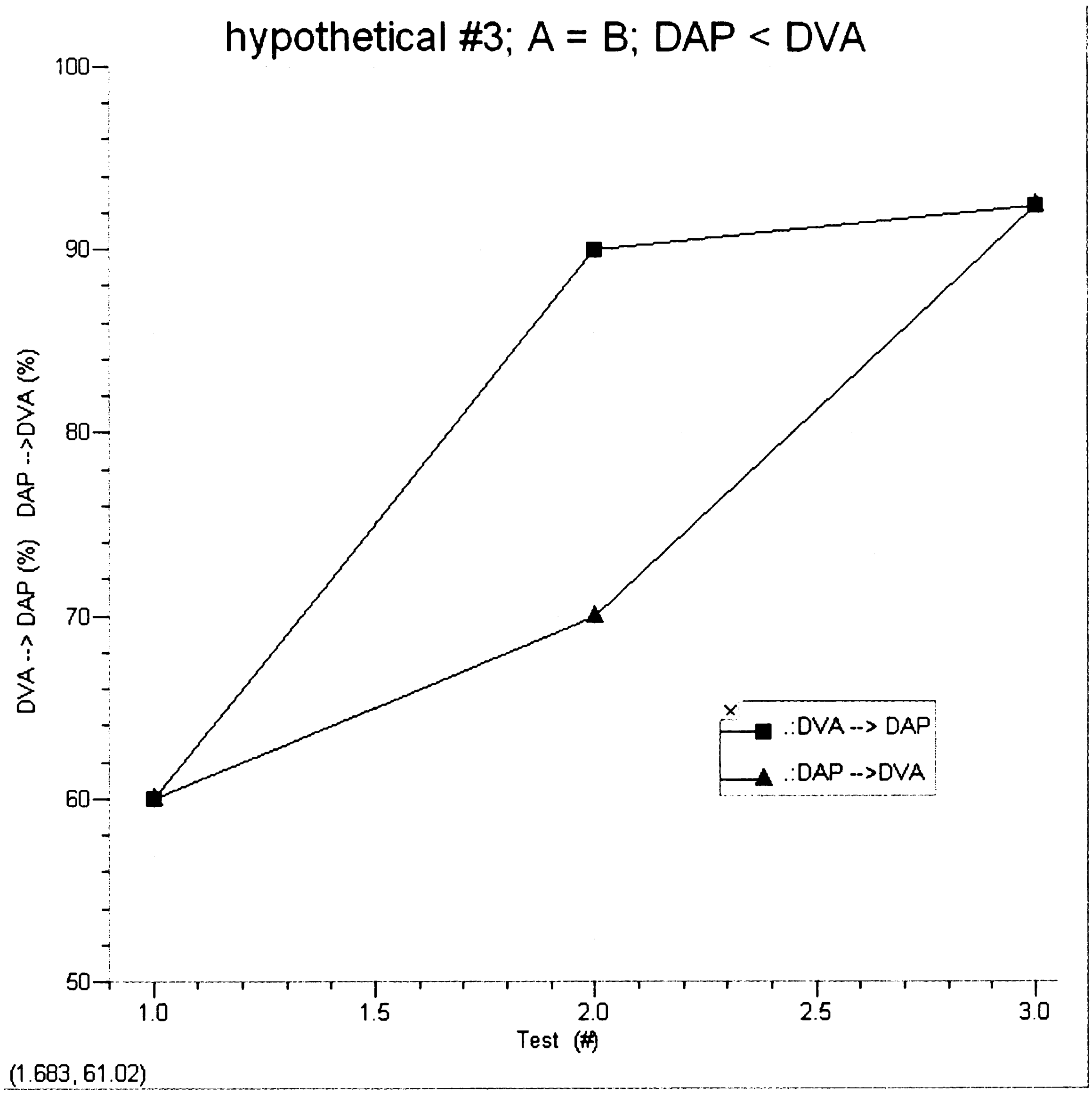
hypothetical #1; equal groups; DVA = DAP, both +
100
80
60
40
DVA --> DAP (%) DAP -->DVA (%)
1.0
1.5
2.0
2.5
3.0
Test (#)
(1.745, 60.4)
.:DVA --> DAP
.:DAP -->DVA

Appendix 6



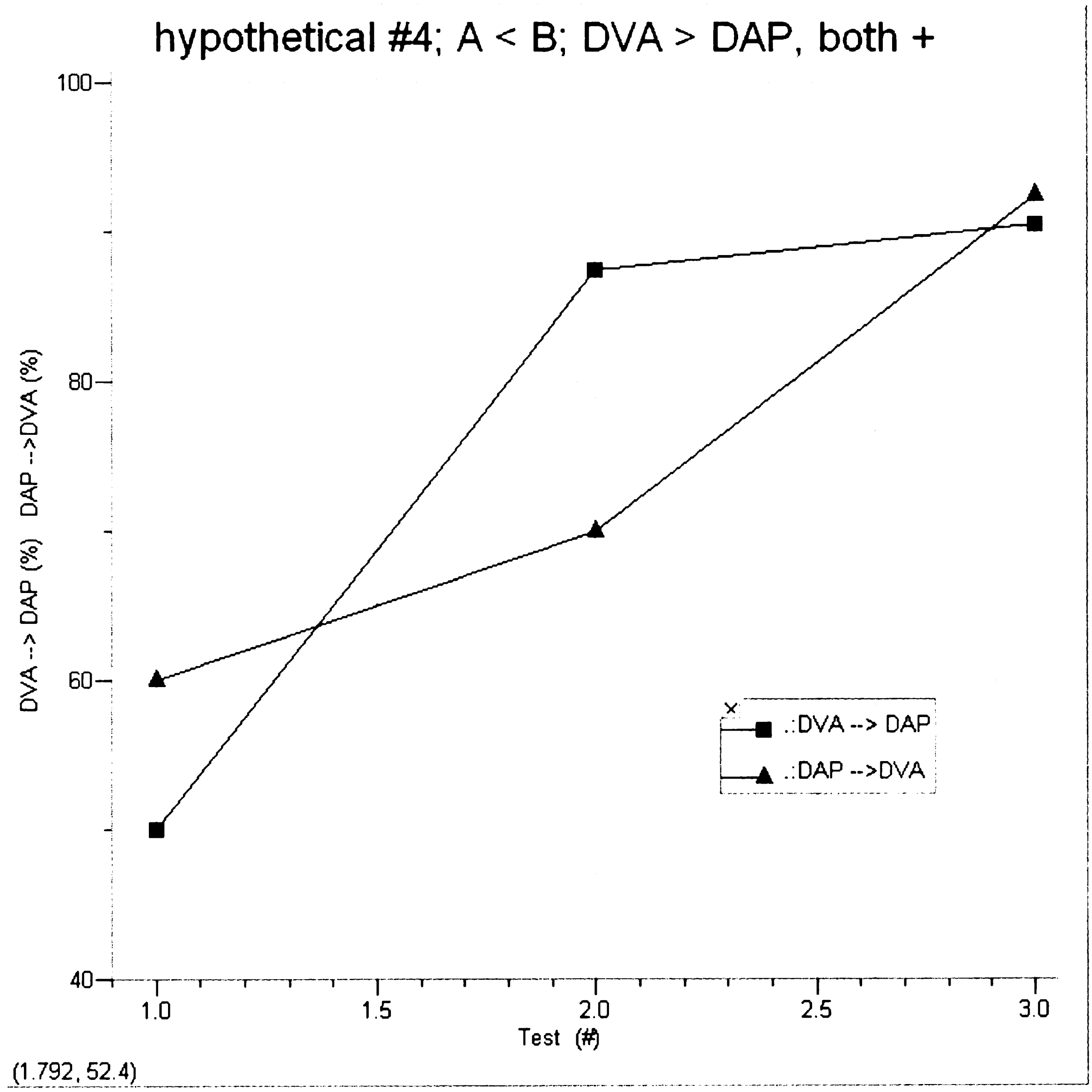
hypothetical E-2; A < B; DVA = DAP
100
80
60
40
DVA --> DAP (%) DAP -->DVA (%)
1.0
1.5
2.0
2.5
3.0
Test (#)
(1.667, 56.1)
.:DVA --> DAP
.:DAP -->DVA

Appendix 7



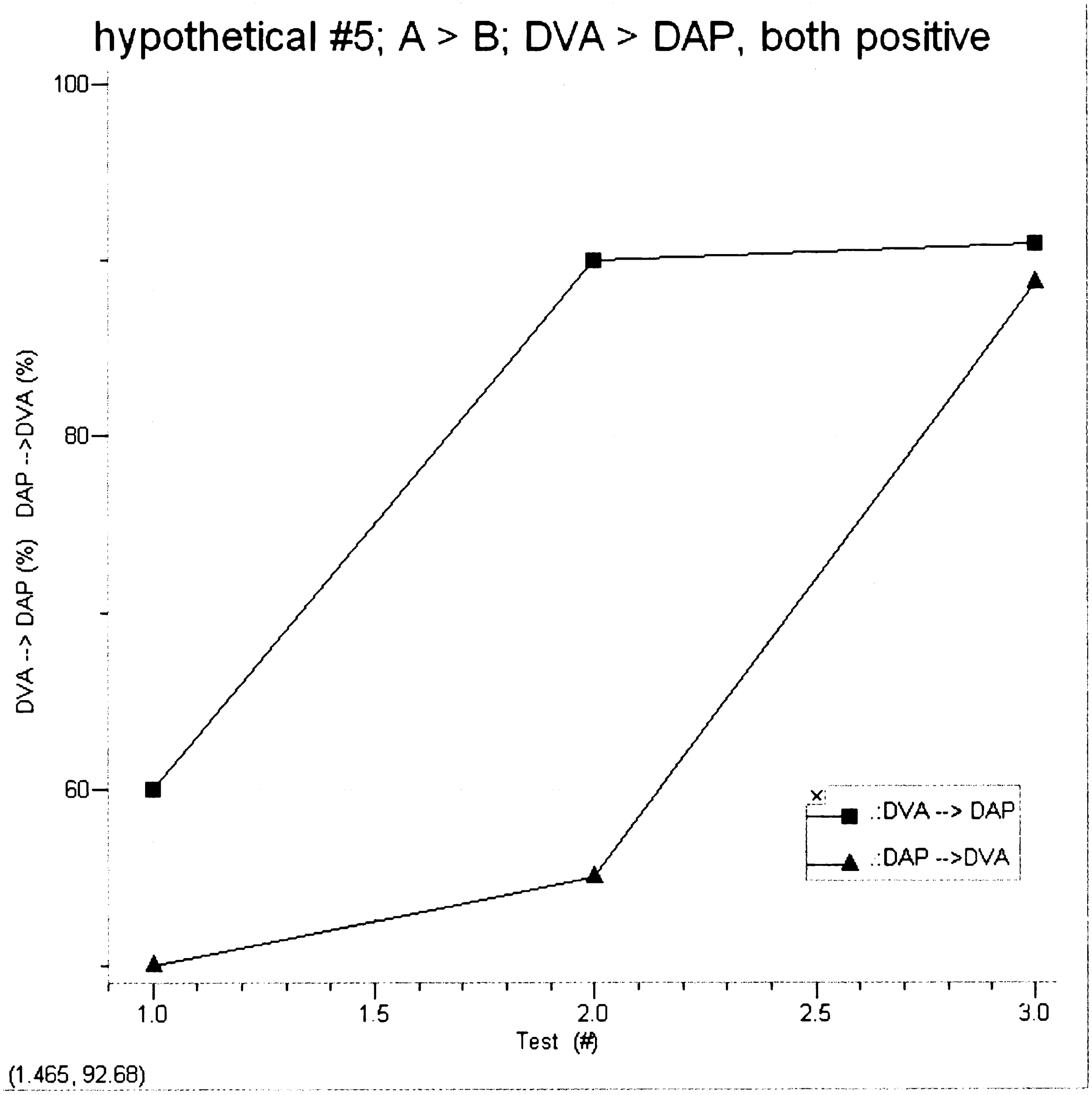
hypothetical #3; A = B; DAP < DVA
100
90
80
70
60
50
DVA --> DAP (%)   DAP -->DVA (%)
1.0
1.5
2.0
2.5
3.0
Test (#)
(1.683, 61.02)
.:DVA --> DAP
.:DAP -->DVA

Appendix 8



hypothetical #4; A < B; DVA > DAP, both +
100
80
60
40
DVA --> DAP (%) DAP -->DVA (%)
1.0
1.5
2.0
2.5
3.0
Test (#)
.:DVA --> DAP
.:DAP -->DVA
(1.792, 52.4)

Appendix 9


hypothetical #5; A > B; DVA > DAP, both positive
100
80
60
DVA --> DAP (%) DAP -->DVA (%)
1.0
1.5
2.0
2.5
3.0
Test (#)
(1.465, 92.68)
x:
.:DVA --> DAP
.:DAP -->DVA

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