

TECHNOLOGY AND STUDENT UNDERSTANDING OF KINEMATIC GRAPHS IN
THE PHYSICS CLASSROOM

by

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A professional paper submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2013

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July 2013

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ABSTRACT

Kinematic graphs play an important role in students' understanding of basic physics' concepts dealing with motion. Often these graphs are difficult for students to interpret and connect with the real world. This project investigated how video analysis software and an educational video game could assist students' understanding of these graphs. While students did increase their understanding of kinematic graphs, further improvement can be made.

INTRODUCTION AND BACKGROUND

I teach high school physics at Washington High School in Sioux Falls, S.D. Our school is diverse by South Dakota standards. According to Washington's 2010-2011 data profile, the school enrolled 2,083 students (Demographic Data, 2011). In the student population, Caucasian, African American, and Hispanic students made up 72.4%, 13.7%, and 6.6% respectively. Thirty-eight percent of students received free or reduced lunch. The school embraces its diversity, creating a positive learning environment. Students in the physics classes are all juniors or seniors. Students have a wide range of mathematical and science background and skills. The students, for the most part, are interested in learning and curious about how the world works. Classes seem to go well and there are relatively few behavior problems.

My favorite topic to teach in physics has always been kinematics: the study of motion. It is always taught at the beginning of the year when teachers and students are fresh and energetic. We take advantage of the nice weather to go outside to measure the velocity of passing cars, shoot bows and arrows, and drop objects off the roof of the school. We talk about position, velocity, and acceleration, trying to relate them to the motions that we observe. The rest of the year-long physics course rests on the understanding of these concepts. A student who does not fully understand velocity and acceleration will struggle with Newton's Laws, momentum, and energy.

Each year, students seem engaged and enthusiastic and I am confident they are grasping the new concepts. The class invests a lot of time and energy striving to understand and find the connections between position, velocity, and acceleration. Yet, when the school year moves on and we come to study Newton's Laws, I am inevitably

disappointed with my students' lack of understanding. To them, velocity and acceleration return to being just motion, with no discernible difference between the two concepts. I end up re-teaching and explaining what I thought was already known.

One effective way to show the connections between position, velocity and acceleration is with kinematic graphs. These graphs quickly and clearly describe the motion of an object. A person walking at a constant velocity of three meters per second could be described, for example, with a simple displacement time graph (Figure 1). Once students learn to understand these graphs, they can provide a lasting impression on the meaning and connections between position, velocity, and acceleration. The difficulty is getting students to look at a graph and connect it to actual physical motion, or to be able to look at actual physical motion and connect that to a graph.

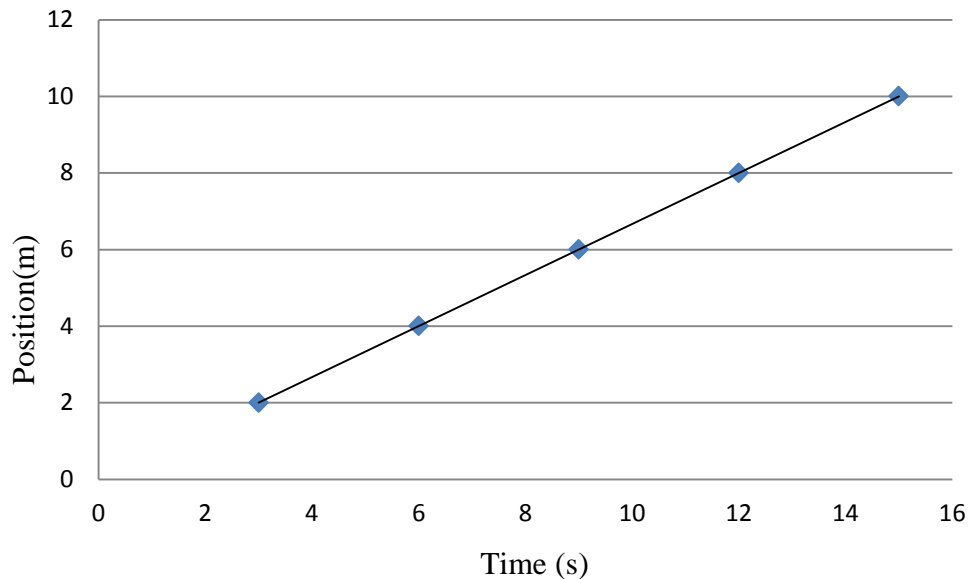


Figure 1. Displacement as a function of time.

Incredibly powerful tools are now available to help students make the connection between a graph and the real world. One tool is video analysis software. Video analysis

software makes it possible for students to watch a video of motion and simultaneously see a graph of that motion. They can look at a specific shape or point in a graph and see exactly what happened in real life to produce that result. I wanted students to create and analyze their own world videos.

Video games are another tool that can help students understand kinematic graphs. These games share many of the same benefits of video analysis. Students can see motion from an animation and watch the graph being created at the same time. Games make learning fun, sometimes to the point that students forget they are learning during the process.

As I thought about the many ways to assist students in understanding kinematic graphs, I was led to the focus of this classroom-based action research project. My primary focus question was: What are the effects of using technology on student understanding of kinematic graphs?

CONCEPTUAL FRAMEWORK

The ability to create and interpret graphs is critically important, not only to the understanding of kinematics, but as a skill students will use for the rest of their lives. McDermott, Rosenquist and Van Zee (1986) studied student interpretations of graphs over a period of several years. They wrote:

...we believe that facility with graphing can play a critical role in helping students deepen their understanding of the kinematical concepts. However, the benefits to students of emphasizing graphs in a physics course extend beyond their application to the material covered. For most students taking physics either in high school or

in college, an ability to work with graphs is likely to be more useful in future academic work than knowledge acquired about any specific topic (p. 513).

Kinematic graphs describe motion by plotting how variables like position, velocity and acceleration change over time. Student difficulties with these graphs are not always linked to inadequate math skills, but the inability to connect the graphical representation to physical actions (McDermott et al., 1986). The first common mistake students were shown to make involved understanding the difference between the height of a graph and its slope. Students were asked which object, A or B, had the greatest velocity at $t = 2\text{s}$ (Figure 2). Many students incorrectly chose object B, because at a time of two seconds, line B was higher than line A. Students also incorrectly chose four seconds as the time when the two objects were traveling at the same speed. To answer the questions correctly, one must realize that the slopes of the lines indicate velocity. Because the slope of line A is steeper than line B, object A must always be traveling faster than object B (McDermott et al., 1986).

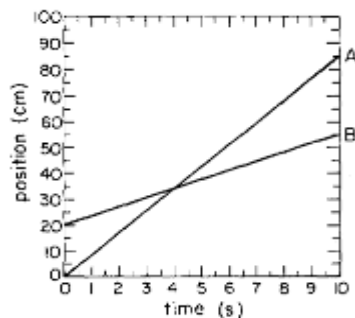


Figure 2. Position Time Graph, (McDermott et al., 1986).

Students also found difficulty in interpreting changes in height and slope.

Students were asked to look at Figure 3 and decide where the motion was the slowest,

where it was speeding up, slowing down and turning around. Students struggled to answer the questions, often answering D for the slowest point and G for slowing down. Again this shows that students were looking at the height instead of the slope of the graph (McDermott et al., 1986).

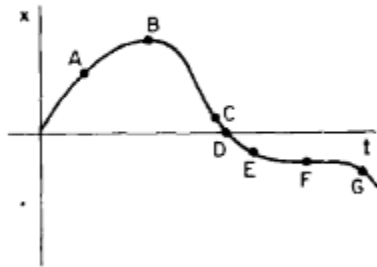


Figure 3. Position Time Graph, (McDermott et al., 1986).

Additional mistakes included the inability of students to separate the shape of a graph from the path of motion and difficulty connecting graphs to the real world. A curriculum was developed that forced students to work with and investigate graphs alongside motion. The curriculum included activities in which students were asked to create motion with ramps that would model a graph that was presented to them. This was effective in increasing the students' understanding of graphs. It forced them to analyze each part of a graph and connect it to a real-world situation. These researchers also found that confronting students with position-versus-time, velocity-versus-time, and acceleration-versus-time graphs simultaneously forced students to deal with the differences between them (McDermott et al, 1986).

Video analysis software has also been shown to improve a students' ability to work with and understand graphs. Students who use video analysis have shown a higher

aptitude for understanding kinematic graphs and connecting them to real-world situations (Struck & Yerrick, 2010). Software such as *Logger Pro* can be easily used to analyze motion in a video (Vernier Software, 2012). Position-, velocity-, and acceleration-versus time graphs can be created simultaneously alongside the motion in the video.

There is a delay from the time students create a video until the time that they see the graphs. Brasell (1987) found that such delays can have a detrimental effect on students' understanding of kinematic graphs. However, this delay may be over-stated. Later studies found no significant reduction in student learning with a time delay between when students first saw a motion and then the corresponding kinematic graph. The important factor may involve the students' level of involvement in creating the motion and graphs, not the time delay between the motion and graph (Beichner, 1990).

One advantage of video analysis is the ability to replay a video. Students who create a video can watch the motion multiple times while plotting points to create a motion graph. Another advantage is that students spend a lot of time on task with video analysis. Creating videos and analyzing them on a computer gives students time to contemplate the concepts that are being presented (Struck & Yerrick, 2010).

These videos can come from many sources. They can be pre-made by the teacher, found on the internet, or created by the students themselves. The videos can be from real-world events or animations. Successful student projects have even used cartoon videos to investigate projectile motion and the acceleration due to gravity (Laws & Pfister, 1998). The programs are easy to use and have been shown to enhance student attitudes towards learning a difficult topic (Escalada & Zollman, 1997).

The effect of video analysis has been shown to improve student learning when it is integrated into the class. Beichner (1996) examined several different classes that used video analysis to varying degrees. The classes were ranked from zero to six, with zero indicating no exposure to video analysis and six indicating that students had vast experience with it, including labs and demonstrations. Students were given the Test of Understanding Graphs-Kinematics (TUG-K). The test was designed specifically by Dr. Beichner to assess students' understandings and misconceptions with kinematic graphs. The results of the different groups showed improved mean scores on the TUG-K for the groups that spent more time with video analysis. The more the students were engaged with the video analysis, the more positive the impact it had on student scores. The largest gains were made in the classes that used many detailed video labs in which students analyzed the motion with computers rather than watching a teacher demonstration. The conclusion: in order to have the desired effect, the software and video analysis must be integrated into the curriculum. Simply tacking on a video or two as a demonstration will not lead to an improvement. In order to have the greatest return, students must have the opportunity and time to work with the video analysis software themselves (Beichner, 1996).

The motion that students analyze in videos is closely related to some deep-seated misconceptions that students have about how and why things move. Wenning (2008) cites a classic example of a commonly held misconception: that an object undergoing acceleration cannot be at rest. He contends that what we learn is selected by our memories to fit into the schema that already exists in the brain. If what we learn doesn't fit into our previous conception of how the world works, our brains can reject it. These

alternative conceptions can be very difficult to dislodge. The Chicago ITQ Science Project studied the success of effective teachers in dealing with students' alternative conceptions. These teachers followed a model of elicit, confront, identify, resolve and reinforce. A key part of this model is to resolve the discrepancies students observe between their old conceptions and the new concepts being taught. Teachers should make extensive use of a student's prior knowledge when trying to resolve these discrepancies. Students need to be confronted with a new concept that must be fostered by the teacher (Wenning, 2008). Digital displays of motion with kinematic graphs can present students with a static picture that represents an entire motion of an object (Escalada & Zollman, 1997). This gives students a chance to confront and resolve some misconceptions they have about motion.

Spatial and visual thinking skills are a key component to being able to solve kinematic problems in physics. The amount of visual and spatial information a student can maintain in working memory is limited and varies from student to student. Many students have trouble creating visualizations of motion needed to solve many of these problems. Visuals from technology have been shown to help students who cannot visualize for themselves (Kozhevnikov, Motes & Hegarty, 2007).

It has been shown that, in some cases, virtual labs and simulations can be more effective than real-world labs. The amount of peripheral information that is needed to understand real-world situations sometimes confuses students. Experts in a field more easily decipher what information is relevant and important and what information can be ignored. Students learning a new topic often lack the ability to filter through all of the information the real-world labs offer. Simulations often cut through this extra

information, simplifying results and allowing students to focus on important concepts (Finkelstein et al, 2005).

METHODOLOGY

The classroom research project was conducted over five weeks and spanned physics units on kinematics and momentum. Through the use of video analysis software and playing an educational video game, the treatment sought to improve students' understanding of kinematic graphs. Students from four physics classes were included ($N = 84$). The video software used was Vernier Logger *Pro* 3. The video game played was *The Universe and More* (Blackman, 2012). Students worked in groups of two with the video software and worked independently on the video game. The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

To gain baseline data on the students' understanding of kinematic graphs, students took the TUG-K test before and after the treatment (Appendix A). The test includes 20 questions that assess understanding of various kinematic graphs. All questions include a multiple-choice question pertaining to a graph and five possible answers from which to choose. A histogram was created to show the distribution of scores for the pre- and post-test.

Three specific questions were chosen because they represented concepts that were a focus of the treatment. Each question was scanned to determine not only the percentage of correct answers, but also the percentage of each individual incorrect answer. This was done to look for misconceptions held by a large number of students. The answers students gave for these three questions were graphed.

One focus of the treatment was for students to be able to calculate velocity from the slope of a position-time graph. Question four accessed this concept (Figure 4).

4. The following figure shows the position-versus-time graph of an object. The velocity of the object at $t = 2$ s is:

- A) .4 m/s
- B) 2m/s
- C) 2.5 m/s
- D) 5 m/s
- E) 10 m/s

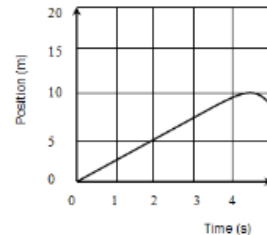
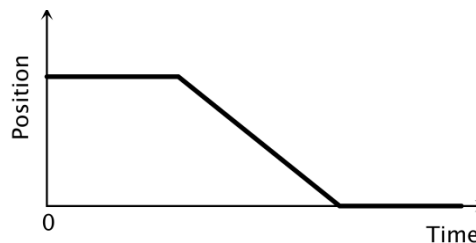


Figure 4. Question four of the TUG-K Test, (Beichner, 010).

Another focus of the treatment required students to look at a position-time graph and be able to interpret the motion it represents. Question six accessed this concept (Figure 5).

6. The following shows the position-versus-time graph of an object's motion. Which sentence is a correct interpretation?



- A) The object is moving at a constant velocity. Then it slows down and stops.
- B) The object doesn't move at first. Then it rolls forward down a hill, and finally stops.
- C) The object rolls along a flat surface. Then it rolls forward down a hill, and then finally stops.
- D) The object doesn't move at first. Then it moves backwards, and then finally stops.
- E) The object moves along a flat area, moves backwards down a hill, and then it keeps moving.

Figure 5. Question six of the TUG-K Test, (Beichner, 2010).

The third concept on which the treatment focused was for students to be able to match a velocity-time graph to a position-time graph. Question eight accessed this concept (Figure 6).

8. The figure to the right represents the position versus time of an object's motion during a 5 s time interval. Which of the following graphs of velocity-versus-time would best represent the object's motion during the same interval?

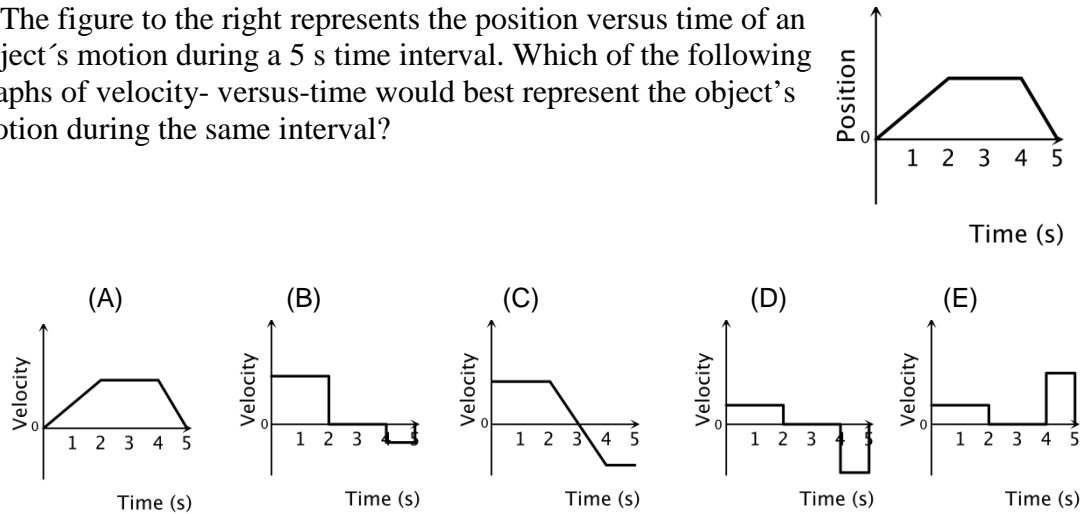


Figure 6. Question six of the TUG-K Test, (Beichner, 2010).

The first lab spanned two days. On the first day, students created five videos. The videos consisted of a toy car moving at a constant speed, a ball being dropped, a racquet ball bouncing, a ball being kicked, and a ball being tossed in the air. Before making each video, the class discussed the motion of the object. Then each student predicted position and velocity graphs on paper. The next day, the students analyzed the videos and created graphs with video analysis software. They sketched the correct graphs next to their predictions and, for each pair of graphs, were asked to reflect on what they learned.

Following the lab, the next two class periods were dedicated to playing *The Universe and More* (Blackman, 2012). This video game shows an object that moves according a velocity and acceleration set by the student. Students attempt to match kinematic graphs given to them on the screen. The graph of the motion set by students

shows up on the screen. If the students correctly set these conditions, their graph is perfectly overlaid on top of the original graph and the students can move on to another level. Students were told to try to find ways to predict what conditions could match the graph before attempting each level.

The final part of the treatment involved the conservation of momentum. Students were given video analysis data of low-friction carts that contained a spring mechanism that pushed the carts away from each other. The carts were labeled Cart A and Cart B. From looking at the position-versus-time graphs, students had to find a velocity for each cart (Figure 7). Students were given access to Cart A to find its mass. From this data, students needed to determine the mass of the other cart. Students were given the Video Analysis Worksheet that contained the graphs and leading questions to solve for the mass (Appendix B).

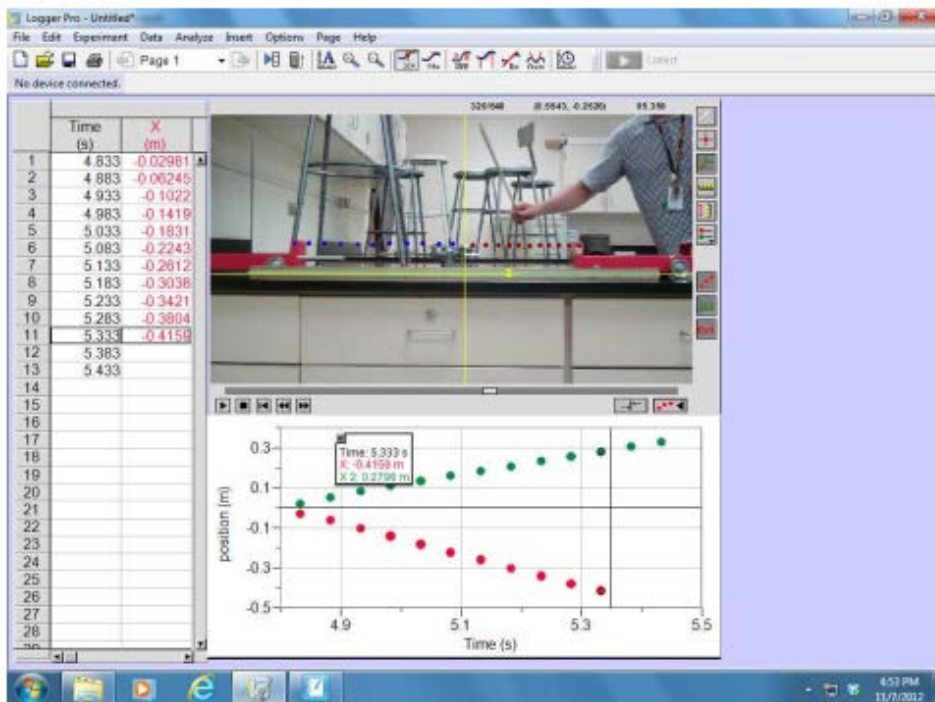


Figure 7. Vernier Logger Pro 3 Screen Capture.

The next day, students were given Position-Time Graph One (Appendix C). The position-time graphs given to the students represented a fast cart moving in the positive x direction and a slower cart traveling in the negative x direction. They were given 1kg masses and told to recreate the motion described by the graph that they had been given. By adding mass to one or more of the carts, students could adjust the velocity of each cart after the spring was released. Students then videotaped their carts and analyzed the videos to see if the motion of their carts matched the graphs given to them. Groups that finished early were given Position-Time Graph Two and repeated the process (Appendix D). The graphs created by the video analysis software were compared to the graphs given to the students at the beginning of the lab. Students reflected on their success or failure in matching the given graph. Each group turned in an electronic copy of their video and corresponding graphs from the *Logger Pro* software. These student artifacts were used as a formative assessment. The videos and graphs were examined to determine how closely they matched the original graphs.

The video analysis graphs created by the students were judged to match if the slopes of the lines were reasonably similar to the slopes of the graphs given to them at the beginning of the lab. Small discrepancies were allowed due to inconsistencies in the carts. The percentage of successfully matched graphs was calculated.

At the end of the unit, students were again given the TUG-K test so that their scores could be compared to the pre-test. Each question was again analyzed to determine the percent of students who chose each multiple-choice option.

Students were given the Student Preference Survey to gauge their opinions about learning with different types of technology (Appendix E). They were asked to rank (from

most-favorite to least-favorite) the various learning methods: labs with video analysis; labs without video analysis; listening to a lecture; and playing a video game. The percentage of students who chose each type of learning activity as their favorite method was placed in a bar graph.

After the test, five students were chosen for an interview. The students were asked about their thought process related to individual questions on the TUG-K test in order to learn what possible mistakes students were still making when analyzing kinematic graphs. Students were also asked to describe what teaching methods they preferred and what teaching methods they thought were most effective.

On the Effectiveness Survey (Appendix F), students were asked to rank the same learning methods as to their effectiveness; the method from which they learned the most to the method from which they learned the least. The number of students who chose each learning method as their favorite was graphed. The results were analyzed to look for correlations between students' favorite activities and the ones they found the most effective. These data sources, as well as those listed above are summarized with my focus questions in Table 1.

Table 1
Data Triangulation Matrix

Research Questions	Data Source #1	Data Source #2	Data Source #3
What is the effect of technology use on understanding kinematic graphs?	TUG-K Pre- and Post- Test	Student-Created Videos and Graphs	Student Effectiveness Survey
Does the use of video analysis assist in learning physics topics beyond kinematics?	Student-Created Videos and Graphs	Student Effectiveness Survey	Teacher Interview
Does the use of technology motivate students to learn kinematic graphs?	Student Preference Survey	Student Effectiveness Survey	Teacher Interview

DATA AND ANALYSIS

Students could not accurately interpret kinematic graphs prior to the treatment.

The average score for all students on the TUG-K pre-test was 27.5 % ($N = 84$) (Figure 8).

The results show scores skewed to the lower end of the distribution. The mean score was 5.5 correct and no student scored higher than 12. The mode was four.

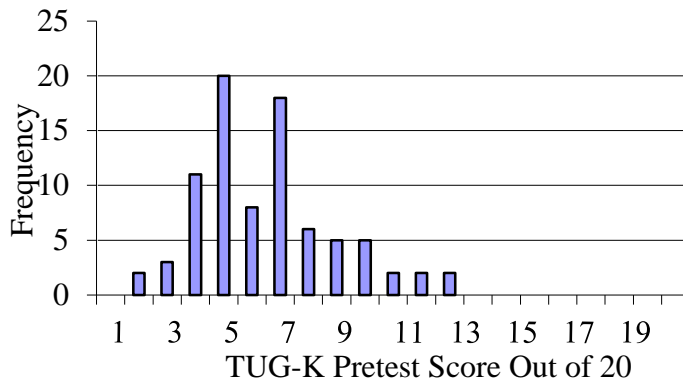


Figure 8. TUG-K pre-test histogram, ($N = 84$).

Students showed an increase in understanding after the treatment. The average score for the TUG-K post-test was 50.5% ($N = 77$). The post-test histogram shows the scores shifted to the right (Figure 9). The mean for the post-test was 10.1, the mode was 9.

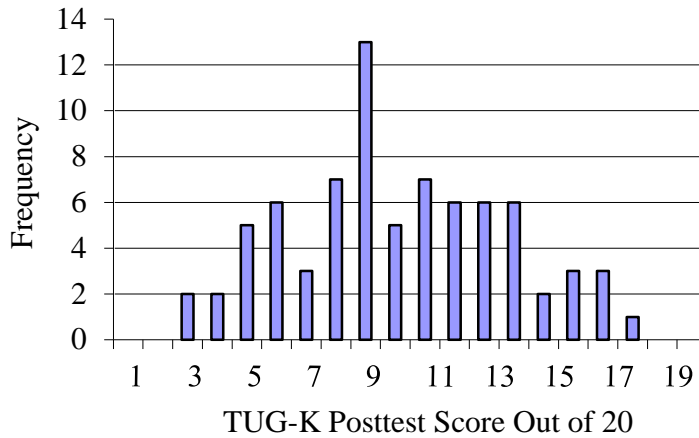


Figure 9. TUG-K post-test histogram, ($N = 77$).

Students improved their ability to read velocity from a position-time graph. Question four from the TUG-K test asked students to calculate the velocity from the position-time graph (Figure 4). The distribution of answers for the pre- and post-test was graphed (Figure 10). The mode for the pre-test was answer D, with 49% of students choosing this answer, ($N = 84$). The mode for the post-test was C, which was the correct answer. The percent of students choosing the correct answer in the post-test was 70%, ($N = 77$).

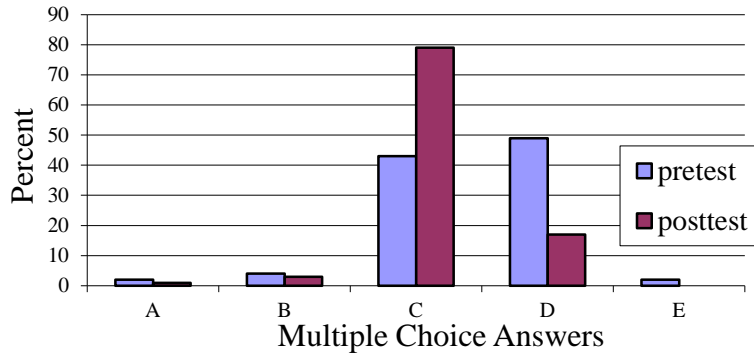


Figure 10. Multiple-choice answers by percentage from Question four of the TUG-K Test: The following figure shows the position-versus-time graph of an object. The velocity of the object at $t = 2$ s is: A) 2 m/s B) 2.5 m/s C) 5.0 m/s D) 10.0 m/s E) 20 m/s.

Students improved their ability to interpret motion from a position-time graph.

Figure 11 shows the breakdown of student answers pre- and post-test for Question six (Figure 5). The mode for the pre-test was C, with 50% of students selecting this answer, ($N = 84$). The mode for the post-test was D, the correct answer, with 62% of all students choosing this answer, ($N = 77$).



Figure 11. Multiple-choice answers by percentage from Question six of the TUG-K Test: The following graph shows the position-versus-time graph of an object's motion. Which sentence is a correct interpretation? A) The object is moving at a constant velocity. Then it slows down and stops. B) The object doesn't move at first. Then it rolls forward down a hill, and finally stops. C) The object rolls along a flat surface. Then it rolls forward down a hill, and then finally stops. D) The object doesn't move at first. Then it moves backwards, and then finally stops. E) The object moves along a flat area, moves backwards down a hill, and then it keeps moving.

Students improved their ability to match a velocity-time graph to a position-time graph. Question eight accessed this skill (Figure 6). The percent of students answering correctly went from 11% in the pre-test to 55% in the post-test. Figure 12 shows the breakdown of answers from the pre-test and post-test. The mode for the pre-test was answer A, with 37% of students choosing this answer ($N = 84$). The mode for the post-test was D, the correct answer.

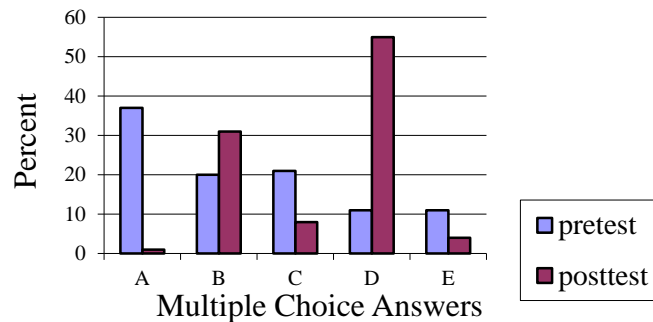


Figure 12. Multiple-choice answers by percentage from Question eight of the TUG-K Test: The figure to the right represents the position-versus-time of an object's motion during a 5 s time interval. Which of the following graphs of velocity versus time would best represent the object's motion during the same interval?

Despite the improvements, students still mistook position-time-graphs for velocity-time graphs in more complex situations. Another question asked students to analyze the position-time graph of two objects at the same time (Figure 13). Answer C incorrectly stated that the two objects would have the same velocity at the point that they crossed each other. If a student answered C, it meant that he or she could not differentiate between a velocity and position graph. The percent of students making this mistake increased from 35% on the pre-test to 45% on the post-test. The percent of students who answered correctly decreased from 37% to 25%. The reason for this increase in selecting the incorrect answer is unknown.

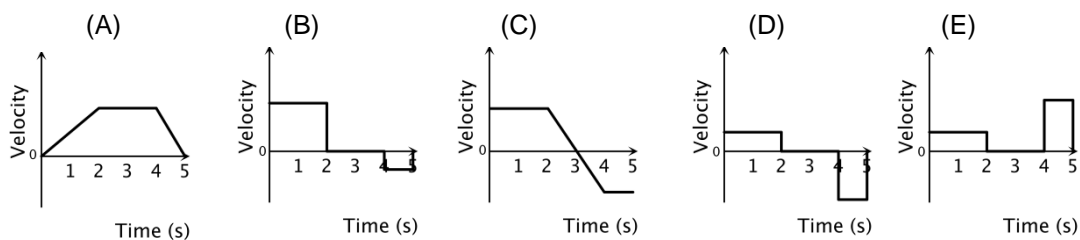


Figure 13. Graphs of object's motion represented by velocity versus time.

In the final lab of the treatment, students were asked to re-create position-time graphs by placing masses on low-friction carts and setting a spring off between the two carts. Sixty-eight percent of all groups successfully created the motion to match the graphs that were given to them. The motion consisted of one cart with a higher velocity traveling in the positive x direction and one slower cart traveling in the negative x direction. The majority of groups that created graphs that did not match simply sent the fast cart in the wrong direction and quickly realized their mistake when they began to analyze their data.

The results of the Student Effectiveness Survey indicated that students preferred to be playing a video game or using the video analysis software. Figure 14 shows student preferred learning activities by percentage.

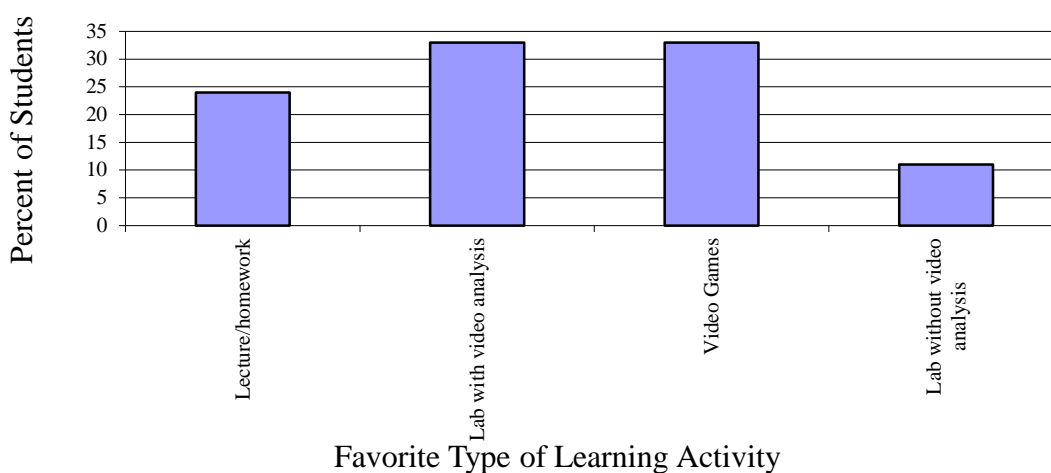


Figure 14. Students' preferred learning activities by percent, ($N = 77$).

Students also ranked video analysis labs highly when it came to the learning methods they felt were most effective. Figure 15 shows the activities the students chose as the most effective way to learn. Even though students enjoyed playing the video game, very few chose it as their most effective way to learn.

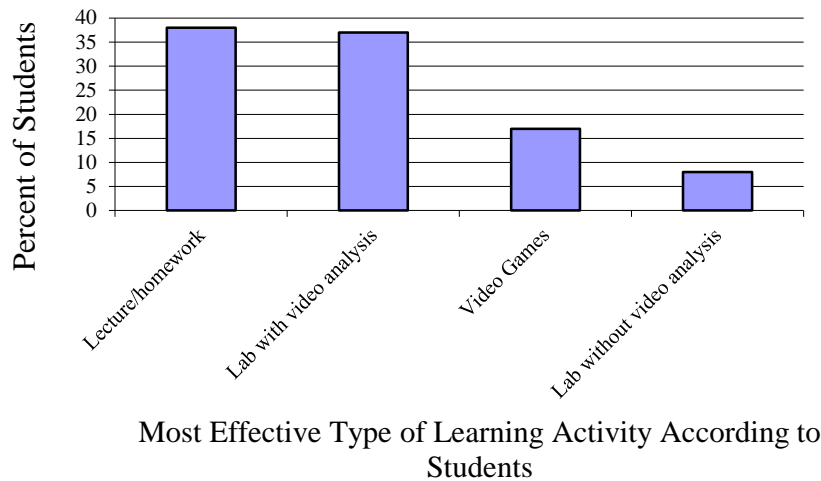


Figure 15. Most effective learning activities according to students by percent, ($N = 77$).

Students who chose video analysis labs for the activity they felt was most effective provided a variety of reasons. They said they liked the visual representation and seeing the video of the lab that they had done the day before. They liked the hands-on activity that came with it, and the autonomy it gave them to create their own answers. One reason that seemed to surface in interviews and survey responses was the extra time that we had taken with the video analysis labs. A typical comment was, “I like to have the extra day to analyze the lab. The video lets me see what we’ve learned come together.”

INTERPRETATION AND CONCLUSION

The data, especially from the TUG-K Test, indicated that technology does help students to better understand kinematic graphs. Many students commented in interviews

and on the survey that seeing the motion slowed down helped them to better understand the concepts. The repetition offered by the video analysis and video games seemed to help the concepts sink in. Students can watch one motion over and over and also see the representative graph. This seemed to help students overcome some common pitfalls when interpreting these graphs.

Students often incorrectly read a position on a position-time graph to calculate velocity instead of calculating the slope. The treatment appears to have helped to correct this mistake. If students answered D for Question four (Figure 4), it indicated that they were reading the position at a specific time instead of the slope of the line to measure the velocity. A student confirmed this assumption when he stated that to answer the question he simply traced his pencil from the graph to the numbers on the y axis. The percentage of students who made this mistake dropped from 49% in the pre-test to 17% in the post-test.

The treatment also seemed to be successful in dispelling another misconception: that the path of motion follows the shape of a position-time graph. Figure 5 shows a question that asked students to interpret the motion represented by a position-time graph. Students answering C incorrectly judged the shape of the position-time graph to directly show its path of motion. When asked why she chose C, one student stated, “It (the graph) looks like a hill you could roll down.” Her statement fits the description for the incorrect answer C. The same student got the question correct in the post-test. This time, in order to answer the question, she used the flat spots on the graph to know when the object was stopped.

Students improved their ability to directly match a velocity-time graph to a position-time graph. Question eight of the TUG-K Test shows students a position-time graph of an object that moves away, stops, and then comes back to the same position. It asks them to match this motion to a velocity-time graph (Figure 6). Most of the students that answered incorrectly in the post-test answered B. This answer also show an object that moves away, stops, and then comes back the original position but changes the relative velocities. This indicates some understanding between position-time graphs and velocity-time graphs.

While I was pleased to see a definite increase in the scores of the exam from pre- to post-test, I was disappointed that the average score was just 50%. Many questions on the test involved using the area under the graph to calculate the change in position or velocity. The fact that this was neither a topic we covered in great detail nor a focus of the treatment could explain some of the poor performance.

Students did not show much improvement on more complex problems in which they were comparing the graphs of two different objects with one object accelerating. I think it would be beneficial to add more in-depth labs that involved more than one object and an object that shows acceleration.

One focus question was to look at video analysis as a method to teach topics outside of kinematics. For example, the video analysis was a great tool to help teach conservation of momentum. In the lab in which students were asked to create motion to match a kinematic graph, they were forced to stop and think of all the different concepts that were involved. Not only did they need to understand that the slope of the line on the kinematic graph indicated the velocity of the objects, but also what direction the graphs

indicated the objects were traveling. They had to understand that the sum of the momentums before the spring was released, causing the carts to move, was going to be equal to the sum of the momentums after the spring was released. And, instead of just writing down answers on paper, they had the opportunity to give their answer in the form of a video of motion that they created. It was an effective way to link the theory to the physical reality.

The video game was a great way to get students motivated. Many students who didn't seem interested in most of the lessons really seemed to enjoy the video game. While the quality of educational video games will likely improve with the advance of technology, I see them serving as a supplement rather than a stand-alone method of education.

Students also seemed highly motivated when they were making their own videos to analyze. The one negative comment I received concerning the video analysis was the amount of time between actually making and then analyzing the video. One way to improve on the labs could be to video capture the motions directly into *Logger Pro* to reduce the delay.

VALUE

Imagine how unbearable a band class would be if 80% of the class was devoted to reading from a textbook and discussing music. Students would not stand for it. The true value in band comes from creating and listening to music. Video analysis software and video games give students a new way to "listen to the music" of physics. I believe that the true value of these technologies is their ability to break down the barriers between the physical world and the theory that exists in books and on the blackboard. The more

seamlessly we can analyze the world around us the more meaningful and enriching physics education will be. I have used video analysis in many units since the treatment, and find that it is a great way to infuse the real world into the classroom. Students have analyzed the video of a balloon launcher to try to calculate where I should stand so they can hit me with a water balloon. We've also investigated suspicious YouTube videos with video analysis to try to discover if they were a hoax or were for real. These kinds of activities can turn the boring and tedious into interesting and useful.

The action research-based classroom project on kinematic graphs has reinvigorated my passion for teaching. I believe that I have gained the skills I will need to progressively improve my students' learning and understanding. Gathering data to critically investigate my own teaching strategies sounds simple in theory, but can seem daunting during the bustle of the school year. I now feel confident that can undertake this, not only for kinematic graphs, but for my entire curriculum.

Like any tool, these technologies can be used effectively or ineffectively. I have a greater appreciation for the complexity involved to create effective ways of using these tools. I believe that these they can be of great benefit to students if used in a student-centered and teacher-guided fashion. Going forward into next year, I would like to use video analysis software in a more student-directed way. One idea would be to give students a video homework assignment. Each student could be given a qualitative kinematic graph and asked to find some motion in the real world that would match the shape of that graph. Students would have to shoot a video of something in the real world, like a car, bicycle or clock, that matched their graph. The power of these technologies is

their flexibility. Any motion that can be videotaped can be analyzed and used for learning. It's a fact that has the potential to expand the classroom in exciting ways.

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APPENDICES

APPENDIX A

TEST OF UNDERSTANDING GRAPHS-KINEMATICS

Test of Understanding Graphs— Kinematics

Instructions

Wait until you are told to begin, then turn to the next page and begin working. Answer each question as accurately as you can. There is only one correct answer for each item. Feel free to use a calculator and scratch paper if you wish. Note that all graphs relate to motion along one direction. So “Position” refers to position along the x -axis, “Velocity” really means the x -component of velocity, and “Acceleration” is along the x direction.

Use a #2 pencil to **record your answers** on the computer sheet, but **please do not write in the test booklet**.

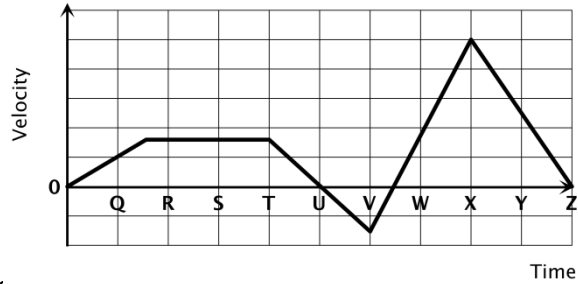
You will have approximately 45 minutes to complete the test. If you finish early, check over your work before handing in both the answer sheet and the test booklet.

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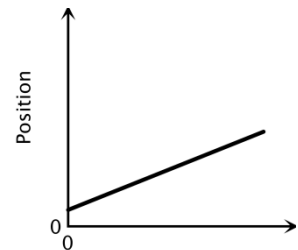
1. The following figure shows the velocity versus time graph of an object. Which of the following options corresponds to the case when its acceleration is the most negative?

- A) V to X
- B) T to V
- C) V
- D) X
- E) X to Z



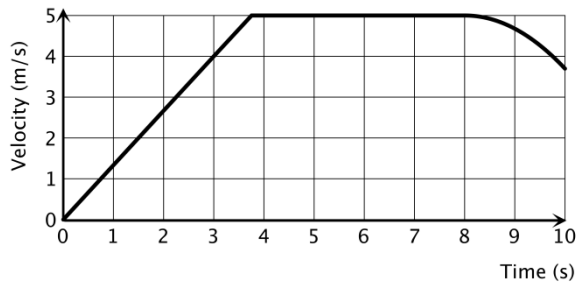
2. To the right is a position-versus-time graph of an object's motion. Which sentence is the best interpretation?

- A) The object is moving with a constant, non-zero acceleration.
- B) The object does not move.
- C) The object is moving with a uniformly increasing velocity.
- D) The object is moving at a constant velocity.
- E) The object is moving with a uniformly increasing acceleration.



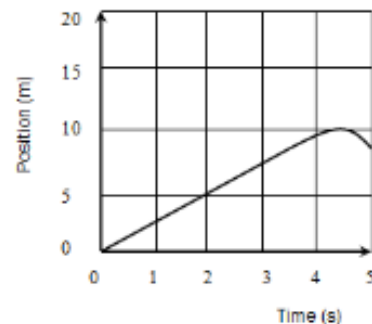
3. An elevator moves from the basement to the tenth floor of a building. The mass of the elevator is 1000 kg and it moves as shown in the velocity-time graph below. How far does it move during the first three seconds of motion?

- A) 0.75 m
- B) 1.33 m
- C) 4.0 m
- D) 6.0 m
- E) 12.0 m



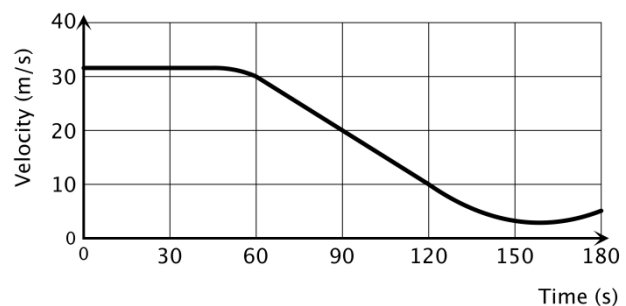
4. The following figure shows the position-versus-time graph of an object. The velocity of the object at $t = 2$ s is:

- A) .4 m/s
- B) 2m/s
- C) 2.5 m/s
- D) 5 m/s
- E) 10 m/s

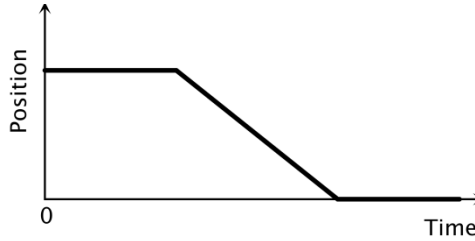


5. The graph below shows the velocity as a function of time for a car of mass 1.5×10^3 kg. What was the acceleration at $t = 90$ s?

- A) -0.22 m/s^2
- B) -0.33 m/s^2
- C) -1.0 m/s^2
- D) -2.0 m/s^2
- E) 20 m/s^2

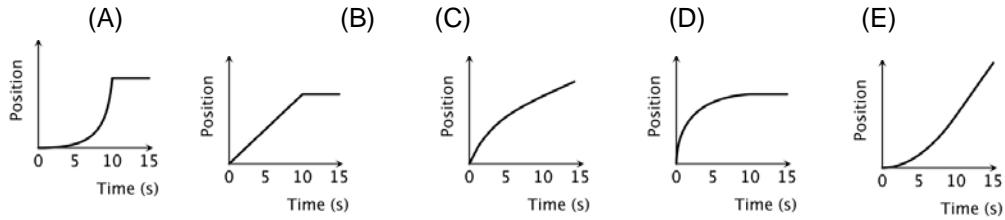


6. The following graph shows the position-versus-time graph of an object's motion. Which sentence is a correct interpretation?

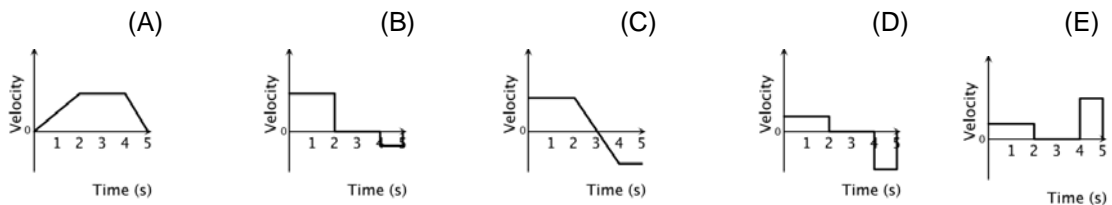
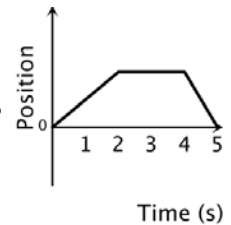


- A) The object is moving at a constant velocity. Then it slows down and stops.
- B) The object doesn't move at first. Then it rolls forward down a hill, and finally stops.
- C) The object rolls along a flat surface. Then it rolls forward down a hill, and then finally stops.
- D) The object doesn't move at first. Then it moves backwards, and then finally stops.
- E) The object moves along a flat area, moves backwards down a hill, and then it keeps moving.

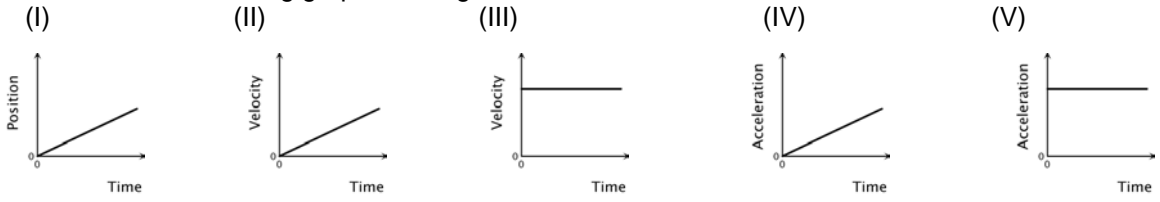
7. An object starts from rest and undergoes a positive, constant acceleration for ten seconds, it then continues on with constant velocity. Which of the following graphs correctly describes this situation?



8. The figure to the right represents the position-versus-time of an object's motion during a 5 s time interval. Which of the following graphs of velocity-versus-time would best represent the object's motion during the same interval?



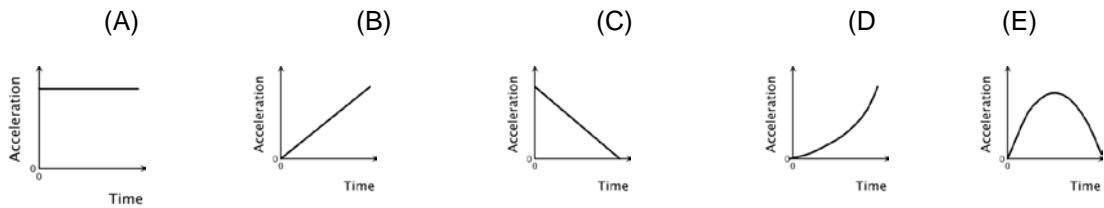
9. Consider the following graphs, noting the different axes:



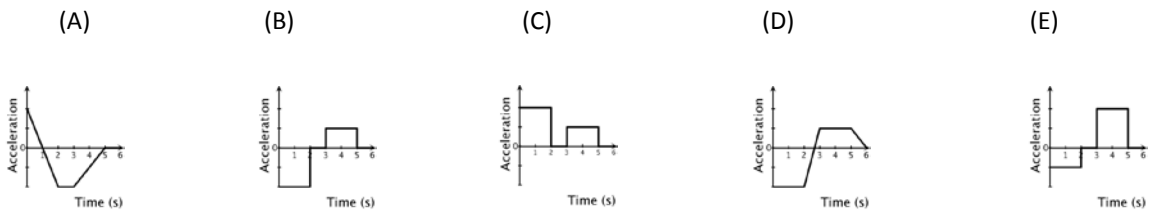
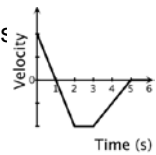
Which of these represent(s) motion at constant velocity?

- A) I, II and IV
- B) I and III
- C) III only
- D) III and V
- E) I, III and V

10. Acceleration-versus-time graphs for five objects are shown below. All axes have the same scale. Which object had the greatest change in velocity during the interval?

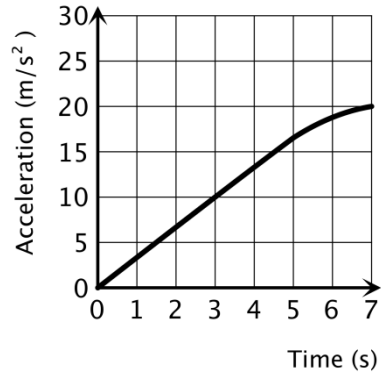


11. The figure to the right represents the velocity-versus-time graph of an object's motion during a 6 s time interval. Which of the following graphs of acceleration-versus-time would best represent the object's motion during the same interval?



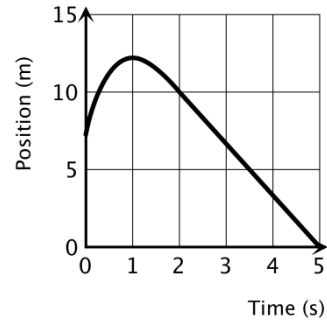
12. The following is an acceleration-versus-time graph of an object. The object's change in velocity during the first three seconds of motion was:

- A) .33m/s
- B) 1m/s
- C) 10m/s
- D) 15 m/s
- E) 9.8m/s



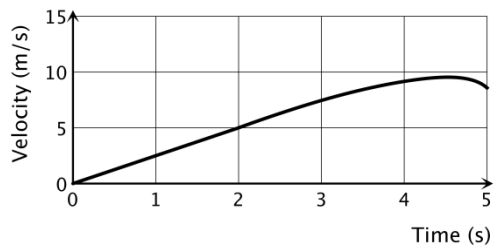
13. The figure to the right shows the position-as-a-function of time for an object. The velocity of the object at $t = 3$ s is about:

- A) -3.3 m/s
- B) -2.0 m/s
- C) -0.67 m/s
- D) -2.3 m/s
- E) 7.0 m/s

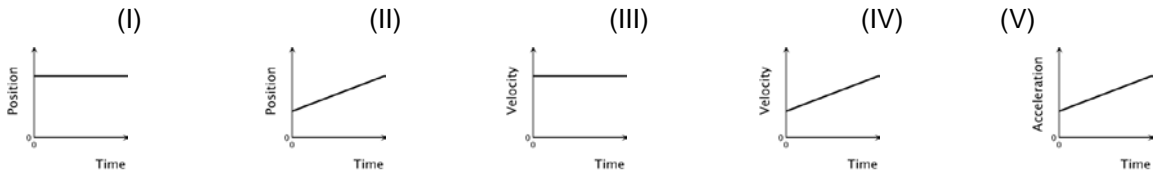


14. The graph below represents the velocity-versus-time graph of an object. If you wanted to know the change in position of the object during the interval from $t = 0$ s to $t = 2$ s, from the graph you would:

- A) read 5 directly off the vertical axis.
- B) find the area between that line segment and the time axis by calculating $(5 \times 2)/2$.
- C) find the slope of that line segment by dividing 5 by 2.
- D) find the value of the distance by multiplying 5 by 2.
- E) find the value by dividing 2 by 5.



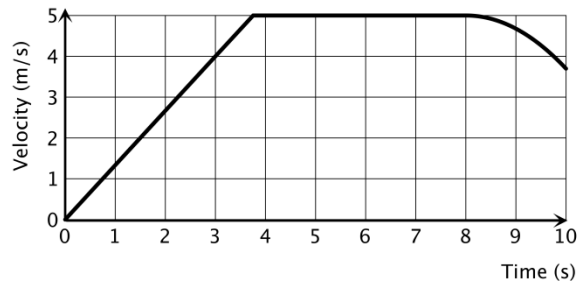
15. Consider the following graphs, noting the different axes:



Which of these represent(s) the object's motion with an acceleration that increases uniformly?

- A) II and III
- B) IV and V
- C) V only
- D) II, IV and V
- E) IV only

16 An object moves according to the graph below:

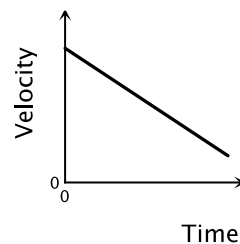


How far does it move during the interval from $t=4$ s to $t=8$ s.

- A) 20m
- B) 5m
- C) 4m
- D) 40m
- E) 12m

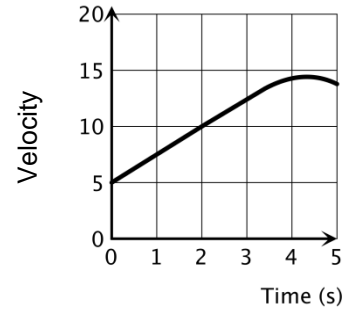
17. The graph to the right represents the velocity of an object's motion. Which sentence is the best interpretation?

- A) The object is moving with a constant acceleration.
- B) The object is moving with a uniformly decreasing acceleration.
- C) The object is moving with a uniformly increasing velocity.
- D) The object is moving at a constant velocity.
- E) The object does not move.



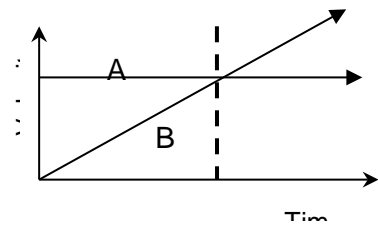
18. The following figure shows the velocity-versus-time graph of an object. The velocity of the object at $t = 2$ s is:

- A) 0.4 m/s
- B) 2 m/s
- C) 2.5 m/s
- D) 5.0 m/s
- E) 10.0 m/s



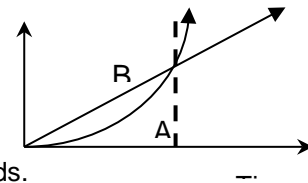
19. The following represents the velocity-time graph for two objects, A and B. Which of the following statements is true?

- A) At $t = 4$ s, object B catches up to object A.
- B) Over the first 4 s, object B has an average velocity of 5 m/s.
- C) At $t = 4$ s, both objects have covered the same distance.
- D) Object A is motionless.
- E) Object B is moving with constant, positive velocity.



20. The following represents the position-time graph for two objects A and B. Which of the following statements is true?

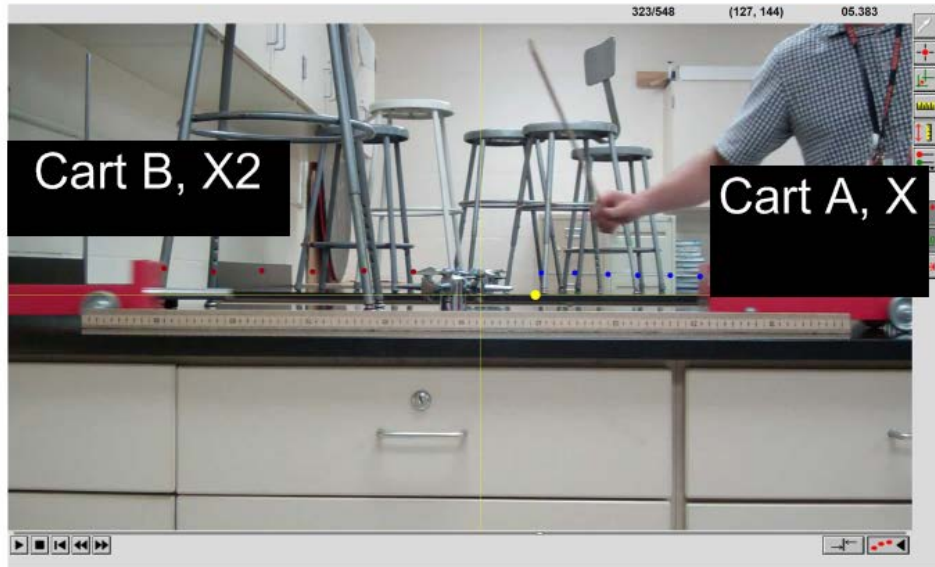
- A) Object B has a greater velocity than object A for the entire time interval 0 to 5 seconds.
- B) Object A has a greater velocity than object B for the entire time interval after seconds.
- C) The velocity of object A equals the velocity of object B at 5 seconds.
- D) Object A has a constant velocity.
- E) Object B is accelerating.



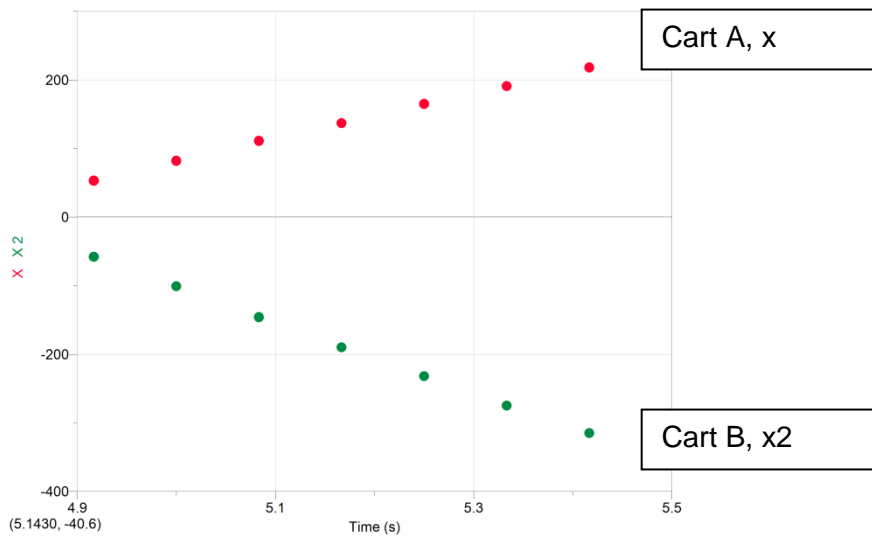
APPENDIX B

VIDEO ANALYSIS WORKSHEET

Video Analysis Spring Carts
Name _____



The picture above shows a video analysis of two spring carts. One cart with a spring pushed off of another cart that did not have a spring. Cart A has some mass added to it. Cart B has no extra mass added to it. Your job is to determine the mass that was added to cart A. A position vs time graph is shown for both carts. The data for each point on the graph is also shown. Answer the questions below showing all your work.

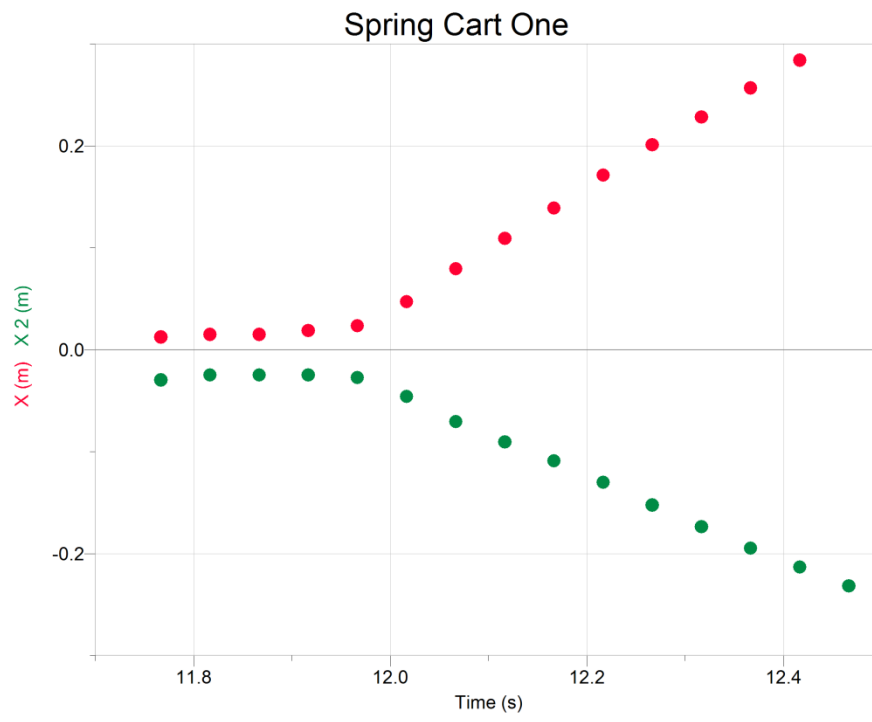


Time(s)	X (m)	X2 (m)
4.917	.053	-.058
5.000	.082	-.101
5.083	.111	-.146
5.164	.137	-.190
5.250	.165	-.232
5.333	.191	-.275
5.417	.218	-.315

1. What is your best approximation of the velocity of cart A?(include your calculations)
2. What is your best approximation of the velocity of cart B? (include your calculations)
3. Summarize a strategy to calculate the mass added to cart A. What other information will you need?
4. Calculate the mass added to cart A.

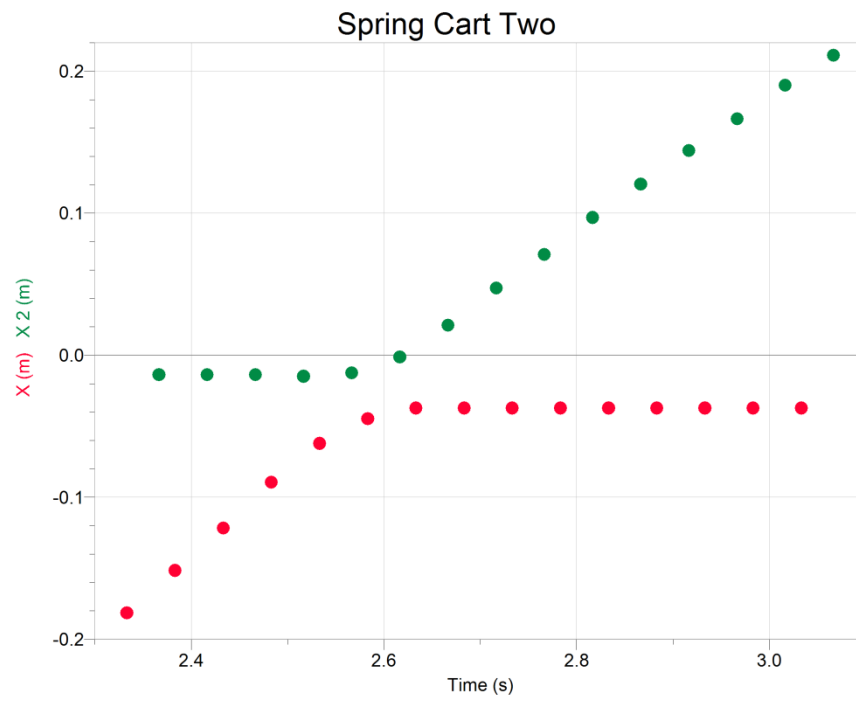
APPENDIX C

POSITION-TIME GRAPH ONE



APPENDIX D

POSITION-TIME GRAPH TWO



APPENDIX E

STUDENT LEARNING PREFERENCE SURVEY

Rank the following learning methods on a scale of 1-4, with 1 being your least favorite and 4 being your most favorite method for learning:

- ___ listening to a lecture and working on problems
- ___ working on a lab with video analysis
- ___ playing a video game (*The Universe and More*)
- ___ working on a lab without video analysis

What reason caused you to choose your most favorite learning method?

What reason caused you to choose your least favorite learning method?

APPENDIX F

STUDENT LEARNING EFFECTIVENESS SURVEY

Rank the following learning methods on a scale of 1-4, with 1 being the least effective (when you learn the least) and 4 being the most effective (when you learn the most):

- ___ listening to a lecture and working on problems
- ___ working on a lab with video analysis
- ___ playing a video game (*The Universe and More*)
- ___ working on a lab without video analysis

What reason caused you to choose the most effective learning method?

What reason caused you to choose the least effective learning method?