Teaching of Newton's Laws:
Force and Motion: The Effectiveness of Demonstrations

Refik Dilber
Ataturk University

Abstract

In this study, we investigated effects of demonstrations on teaching of force and motion concepts compared with traditional instruction. The participants of this study consisted of 68 undergraduate students who taking the course in two different classes from the same teacher. One of the classes was assigned randomly to the control group, and the other class was assigned randomly to the experimental group. During teaching the topic of force and motion concepts in the physics curriculum, demonstrations were applied in the experimental group whereas in the control group traditional instruction was followed for the period of four weeks. As a result, we determined that the experimental group showed better performance than control group in terms of the success.

Introduction

Physics has long been regarded as one of the most abstract and difficult subjects to learn. A common belief is that the students who do well in physics have a special aptitude for learning science and mathematics. It is easy to understand how many might believe that the only students who are going to ''need'' physics are future engineers and physicists. However, instead of reserving physics for a gifted few, many feel that technology offers the chance to change commonly held perceptions about who can or should learn physics (White & Frederiksen 1998). For example, complex systems such as physics can easily be modeled on desktop computers. One prime goal for using computers in the teaching of physics is the opportunity they offer to introduce students to the concepts and methods that characterize today's scientific research (Guisasola et al. 1999). Computer are thus used as a tool for solving problems that would otherwise be very difficult to face, as a means of simulating and visualizing different situations, and also as a means of collecting information, evaluating it and providing rapid feedback (Nachmias et al. 1990; Weller 1995; Gillies et al. 1996; Stewart and Gregory 1997; Gorsky and Finegold 1992). Computer demonstrations make complex systems accessible for students of varying ages, abilities, and learning levels. The computer, instead of the student, can assume responsibility of processing the underlying mathematics in order to let the student begin exploring a complex system by first focusing on conceptual understanding (de Jong & van Joolingen 1998; Penner 2000–2001). The emphasis of this approach is on experiences, rather than explanations, of a domain. Of course, this is not to suggest that explanations are not important. Indeed, much current research points to the advantages of multimedia explanations for learning (Mayer 2002). However, the interactive affordances of computer demonstrations and other modeling environments suggest an educational model based on experiential learning. The role, timing, and influence of explanations while learning science principles need to be reconsidered and reexamined.

The difficulties for students of forming a meaningful understanding of Newton's laws of motion have been the focus of empirical studies over many years (for example Gamble 1989; Hellingman 1989; Heywood and Parker 2001; Osborne 1985; Searle 1995; Watts and Zylbersztajn 1981). It is interesting that most textbook treatments of this topic assume that the notion of what a force 'is' is either self-evident or can be easily dealt with by defining force as a push or pull (Gamble 1989). Arnold Arons (1990) noted that difficulties with language have the potential to interfere with students' developing understanding of this topic, but the actual difficulties that students experience with the term 'force' have received only limited attention from researchers (Hart 2002).

Initially, the role and effect of demonstrations in both high school and college instruction was debated. Demonstrations were thought to be affective aids in increasing student's conceptual understanding in a summary of early opinion literature (McKee at al. 2007).

A novel expansion of the use of demonstrations was an attempt to combine a demonstration assessment, creating what was termed a demonstration assessment. The demonstration assessment is two-step process. First, a demonstration is shown to the students without explanations. Second, an assessment is administered covering the demonstration, asking students to draw conclusions and/or to propose explanations based upon observations made during the demonstration (McKee at al. 2007).

Our past research has shown that the way feedback is represented also matters when learning from demonstrations of physical science concepts and principles (i.e., laws of motion). Participants increased their implicit knowledge of physics when they interacted with a physics demonstration given graphical feedback, but they were unable to demonstrate increased explicit understanding based on the way the feedback was represented (Rieber 1996; Rieber & Noah 1997; Rieber Noah, & Nolan 1998; Rieber et al. 1996). Implicit understanding was measured by participants' performance in a game-like activity whereas explicit understanding was measured using a traditional performance test (i.e., multiple-choice question format). The increase in implicit learning given graphical feedback indicated that representational and associative processing occurred almost exclusively within the visual system. Participants' difficulty in acquiring explicit understanding of the physics principles modeled by the computer was attributed to the highly interactive nature of the discovery-based demonstration. Demonstrations that model physical phenomena (such as physical science) may not provide the learner with sufficient time or guidance for interpreting the continual stream of feedback by both the visual and verbal systems. In other words, the ''video game-like'' quality of the demonstration may have interfered with referential processing by only promoting processing in the visual system and discouraging processing in the verbal system (Rieber et al. 2004).

Microcomputers have a number of considerable advantages over many of the other educational media presently in use. Firstly, students can interact directly with a microcomputer. Thus, provided the software requires it of them, students play a very much more active role in learning with other media. Secondly, students can get individual attention for their specific difficulties from the microcomputer. Thirdly, microcomputers allow students to control the pace et which they work, so that a student who is having difficulty with one particular section of work can take the time needed to master it before moving on to the next section. Microcomputers are currently being used in a number of different ways in science instruction at both secondary and tertiary levels (Hewson 1984).

All too frequently, real world experiences are difficult to repeat in the laboratory, are to complicated for introductory students analyze, happen too rapidly to be seen, can only be observed using complicated instrumentation which obscures the desired phenomena, or are otherwise unexaminable. The ability of the microcomputer to demonstrate this type of phenomenon allows the student to expand his or her range of experience greatly (Hewson 1984).

Computer demonstrations can also be used to provide such discrepant events. This has the additional advantage that students can freely explore the micro world of the program by changing the parameters and variables and visualizing immediately the consequences of their manipulations. Students can interpret the underlying scientific conceptions of the program and compare them with their own conceptions. They can also formulate and test hypotheses and reconcile any discrepancy between their ideas and the observations in the micro world (Bliss and Ogborn 1989).

Computer demonstrations can also be effective tools, easily applied in the schools, in order to support modeling instruction (Jimoyiannis & Komis 2001; Tao&Gunstonea 1999). They constitute open environments that provide students with the opportunity:

- to develop their meaningful understanding about physical concepts and phenomena, through an active process of making hypotheses and testing ideas,
- to employ a variety of representations and express their own ideas about physical phenomena.

In the study, we investigated how computer demonstrations affect the students' understanding of force and motion concepts.

Method

Subjects: The subjects of the study consisted of 68 male and female undergraduate students from two classes of physics course taught by the same teacher in Ataturk University, Turkey. One class was assigned randomly to the experimental group (n = 35) while the other formed the control group (n = 33). While the experimental group was taught by the way of demonstrations, the control group was taught by the way of traditional instruction. The topics concerning force and motion were covered as part of the regular classroom curriculum in the physics course. During the study, each group received an equal instructional time and was provided with the same materials and assignments, apart from the demonstrations in the experimental group. The classroom instruction for both groups involved four 50-min periods per week.

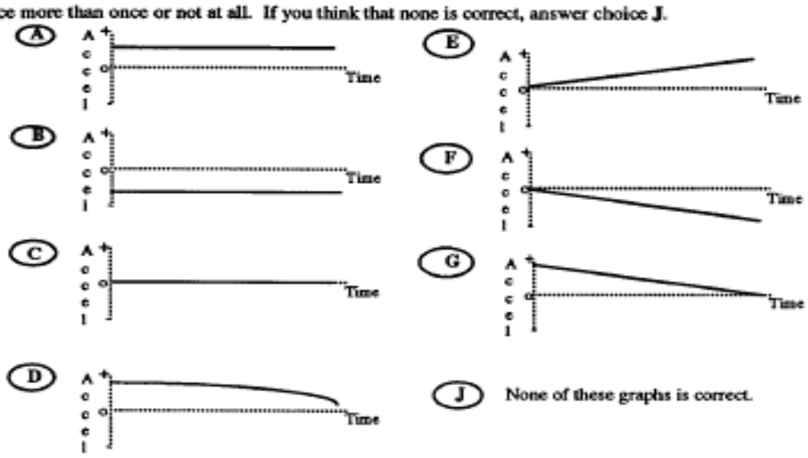
Materials: Two different instruction methods were used in the groups. While computer demonstration was used for experimental group, the traditional instruction was used the control group.

Force and Motion Test (FMT): The FMT test consisted of 34 items. The questions used in this study were collected from the literature (Thornton and Sokoloff 1997). We used only 34 questions of this test. Two examples of the test questions are presented in Figure 1. All questions were translated to Turkish Language and were piloted required modifications were made prior to the administration of the test. The content validity of the test items was carried out by a group consisted of a professor of physics and two research assistants. The reliability (alpha) of the test was found to be 0.75. The final form of the test was administered to both groups as a pre and post-test before and after the treatment.

Questions 22-26 refer to a toy car which can move to the right or left along a horizontal line (the + distance axis). The positive direction is to the right.

Different motions of the car are described below. Choose the letter (A to G) of the acceleration-time graph which corresponds to the motion of the car described in each statement.

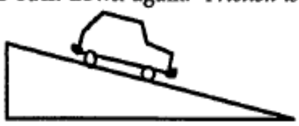
You may use a choice more than once or not at all. If you think that none is correct, answer choice J.



(J) None of these graphs is correct.

_____22. The car moves toward the right (away from the origin), speeding up at a steady rate.
_____23. The car moves toward the right, slowing down at a steady rate.
_____24. The car moves toward the left (toward the origin) at a constant velocity.
_____25. The car moves toward the left, speeding up at a steady rate.
_____26. The car moves toward the right at a constant velocity.

8-10 refer to a toy car which is given a quick push so that it rolls up an inclined ramp. After it is released, it rolls up, reaches its highest point and rolls back down again. ***Friction is so small it can be ignored.***



Use one of the following choices **(A through G)** to indicate the **net force** acting on the car for each of the cases described below. Answer choice **J** if you think that none is correct.

(A) Net **constant** force **down** ramp
(B) Net **increasing** force **down** ramp
(C) Net **decreasing** force **down** ramp
(D) Net force zero
(E) Net **constant** force **up** ramp
(F) Net **increasing** force **up** ramp
(G) Net **decreasing** force **up** ramp

_____8. The car is moving up the ramp after it is released.
_____9. The car is at its highest point.
_____10. The car is moving down the ramp.

Procedure

In the study, the test concerning force and motion concepts was applied to each group as a pre-test. After that, the researcher lectured the Newton's Laws to experimental and control groups' students for the period of four weeks in classroom. The control group received traditional instruction which involves lessons using lecture/discussion methods to teach concepts. The teacher described and defined the concepts and after the explanations some concepts were discussed, motivated by teacher-directed questions. The majority of the time (60-70%) was devoted to instruction and engaging in discussion stemming from the teacher's explanation and questions.

The demonstrations were used to illustrate physical concepts to the experimental group. The instructor presents the demonstration and focuses on particular aspects of the event to highlight a physical concept and ask the students to understand only that particular event. The demonstration and its related goal offer a concrete reason why we need to study the concepts. In other words, the demonstration and associated learning goals provide at least one answer to the often asked questions why are we doing this? And what purpose does learning this serve? By putting the concept into the context of the demonstration, we have an event that the students can visualize while trying to understand the concept. This visualization can serve as a basis for extending the concept to other physical situations. These demonstrations also help relate the concepts to everyday concrete phenomena: students are asked to visualize and discuss how what they are seeing manifests it self in everyday events. For example, when we demonstrate the role of friction, the students are apt to volunteer the scenario where the absence of friction creates special conditions when they attempt to drive their cars on ice streets. The demonstrations used in the study are related to motion at frictionless and with friction surface, frictionless and with friction motion at sloping down surface, action and reaction forces between bodies and a body which is tossed up in the air. One example of the demonstrations is presented at Appendix B. Macromedia Flash 8 Program was used to prepare the demonstrations and Macromedia Fireworks 8 program was used to prepare pictures of these simulations by the researcher. At the end of the four weeks period, same test was applied as a post test.

Results

In the study, we investigated effectiveness of computer demonstrations on students understanding of force and motion.

The independent group t-test was used in order to investigate the effects of method on students' success of force and motion concepts. The dependent variable was students' achievement of force and motion concepts measured by post FMT test scores (POSTFMA). The independent variable was students' achievement of pre force and motion concept (PREFMA) measured by pre force and motion concept test scores.

Table1. Independent group t-test results for pre and post test scores

PREFMA	N	Mean (34 item)	Standart deviation	t	p
Experimental Group	35	14,71	3,93		
Control Group	33	14,90	3,10	-0,226	>0,05
POSTFMA	N	Mean (34 item)	Standart deviation	t	p
Experimental Group	35	25,57	4,50		
Control Group	33	20,24	3,32	5,52	P<0,05

PREFMA: pre force and motion concept achievement. POSTFMA: Post force and motion concept achievement

As seen in table 1, according to pre-test results, there is no statistical difference between experimental and control groups' achievement. It means that there was no difference between control and experimental groups in terms of knowledge level about the topic at the beginning. Again in table 1, according to the post-test results there is meaningful statistical difference between experimental and control groups' achievement after the treatment. It means that the experimental group who learnt the topic by the way of computer demonstrations is more successful then the control group.

Table 2. Percentage of students' correct answers for each question.

Questions	Experimental group		Control group		Questions	Experimental group		Control group	
	Pre-test (%)	Post-test (%)	Pre-test (%)	Post-test (%)		Pre-test (%)	Post-test (%)	Pre-test (%)	Post-test (%)
1	47	82,3	55,8	67,64	18	38,23	70,58	38,23	50
2	52,94	76,47	44,11	58,82	19	61,76	94,11	55,8	76,47
3	47	79,41	50	61,76	20	55,8	97,05	50	61,76
4	50	94,11	52,94	64,70	21	29,41	70,58	26,47	41,17
5	55,8	97,05	52,94	61,76	22	32,35	55,8	38,23	50
6	58,82	88,23	50	67,64	23	23,52	58,82	32,35	52,94
7	47	73,5	41,17	52,94	24	26,47	61,76	35,29	38,23
8	44,11	76,47	47	55,8	25	47	79,41	50	61,76
9	41,17	67,64	44,11	61,76	26	38,23	61,76	41,17	64,70
10	50	85,29	47	67,64	27	58,82	94,11	55,8	79,41
11	44,11	79,41	38,23	50	28	33,3	58,82	44,11	52,94
12	38,23	67,64	32,35	52,94	29	44,11	76,47	38,23	55,8
13	50	82,3	41,17	50	30	50	82,3	47	67,64
14	58,82	94,11	55,8	79,41	31	52,94	79,41	44,11	55,8
15	50	79,41	52,94	70,58	32	20,58	50	23,52	41,17
16	47	73,5	50	64,70	33	17,64	55,8	23,52	44,11
17	41,17	52,94	47	61,76	34	33,3	64,70	26,47	47

According to results of the table 2, the experimental group showed better performance than control group in understandings of force and motion concepts. While the correct answer percentage of experimental group for pre test was approximately 43.72%, for the post test the correct answer percentage was approximately 75.32%. These results indicated that the success rate of experimental group was considerably increased after treatment. While the correct answer percentage of control group for pre test was approximately 43.31%, for the post test the correct answer percentage reached approximately 58.5%. So it indicated that the success rate of control group which learned the topic in traditional way was increased but only slightly.

Discussion

The purpose of this research was to investigate ways to facilitate or enhance an individual's learning of physics principles while interacting with a computer demonstration. Recent studies indicated that computer has been implemented in restructuring learning environment where by the encouragement of higher-order. Thinking learner is viewed as an active participant in constructing his or her own knowledge rather than just merely being a passive process of receiving information or acquiring isolated pieces of knowledge. Interactive demonstrations are particularly useful because they enable users to explore and visualize the consequences of their reasoning. They give instant feedback in the form of dynamic or numerical representations of how variables are interrelated. These facilities allow students to design and carry out a series of their own experiments, requiring a more sophisticated qualitative appreciations appreciation of problem (Hennessy et al. 1995; Ting Choo Yee and Mohd Yusof Arshad, 2000; Zıetsman, and Hewson 1986).

When learning Newtonian mechanics, understanding the interrelationships of concepts and principles is very challenging. While a demonstration offers students the opportunity to interact with a working model of these ideas, they frequently become disoriented or unable to focus on the most essential cues (Rieber et al. 2004).

In the study, according to post test results the experimental groups' students showed better performance than control groups' students. This result indicated that demonstrations play an important role on students' success of understanding. For example, experimental group students' showed better performance than control group according to post test results. Thanks to the demonstrations, students find a chance to animate force and motion concepts in their mind. So demonstrations play an important role on students' success of understandings. That is to say, demonstrations provide rather effective feedback to students

Conclusion

The results of this research point to a simple yet powerful means of facilitating referential process in a demonstration. This study has shown that when demonstration is used in the classroom teaching students' understandings of force and motion concepts are more enhance than traditional instruction. Science teachers can use often demonstrations in their classroom teaching to enhance students' understandings.

Appropriate application of experience gained through interaction with computer demonstrations is a complex skill. Further research should be conducted to identify and describe additional factors that affect students' ability to solve and visualize problems following computer demonstrations in order to develop improved pedagogical strategies for using them.

For curriculum development is that formative evaluations that include data on the conditions under which students visualize target problems following use of a demonstration can and should be an early component of development projects. Such data should guide and improve both the developer's design of educational computer demonstrations and the teacher's design of learning activities which employ them.

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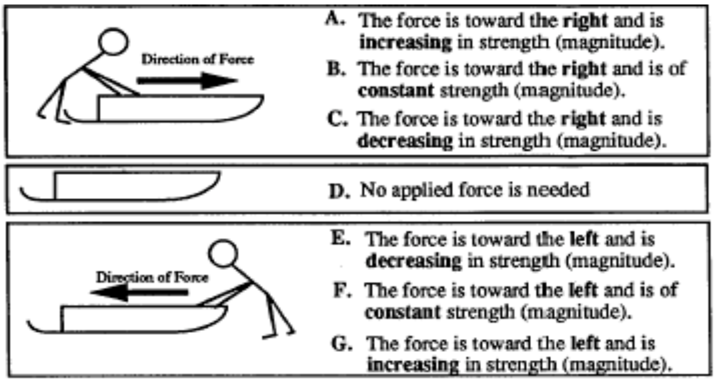
Appendix A: Complete Force and Motion Conceptual Evaluation

Directions: Answer questions 1-43 in spaces on the answer sheet

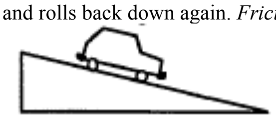
A sled on Ice moves in the ways described in questions 1-7 below. *Friction is so small that it can be ignored.* A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the one force (A through G) which would keep the sled moving as described in each statement below.

You may use a choice more than once or not at all but choose only one answer for each blank. If you think that none is correct, answer choice J.



1. Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)?
2. Which force would keep the sled moving toward the right at a steady (constant) velocity?
3. The sled is moving toward the right. Which force would slow it down at a steady rate (constant acceleration)?
4- Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)?
5. The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity?
6. The sled is slowing down at a steady rate and has acceleration to the right. Which force would account for this motion?
7. The sled is moving toward the left. Which force would stow it down at a steady rate (constant acceleration)?

8-10 refer to a toy car which is given a quick push so that it rolls up an inclined ramp. After it is released, it rolls up, reaches its highest point and rolls back down again. *Friction* is *so small it can be ignored.*



Use one of the following choices (A through G) to indicate the net force acting on the car for each of the cases described below. Answer choice J if you think that none is correct.

A. Net constant force down ramp.
B. Net increasing force down ramp
C. Net decreasing force dawn ramp
D. Net force zero
E. Net constant force up ramp
F. Net Increasing force up ramp
G. Net decreasing force up ramp

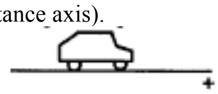
8. The cat is moving up the ramp after it is released.
9. The car is at its highest point
10. The car is moving down the ramp.

Questions 11-13 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (A through G) to indicate the force acting on the coin for each of the cases described below. Answer choice J if you think that none is correct. Ignore any effects of air resistance.

A. The force is down and constant
B. The force is down and Increasing
C The force is down and decreasing
D. The force is Zero.
E The force is up and constant.
F. The force is up and increasing
G. The force is up and decreasing

11. The coin is moving upward after it is released.
12. The coin is at its highest point
13. The coin is moving downward.

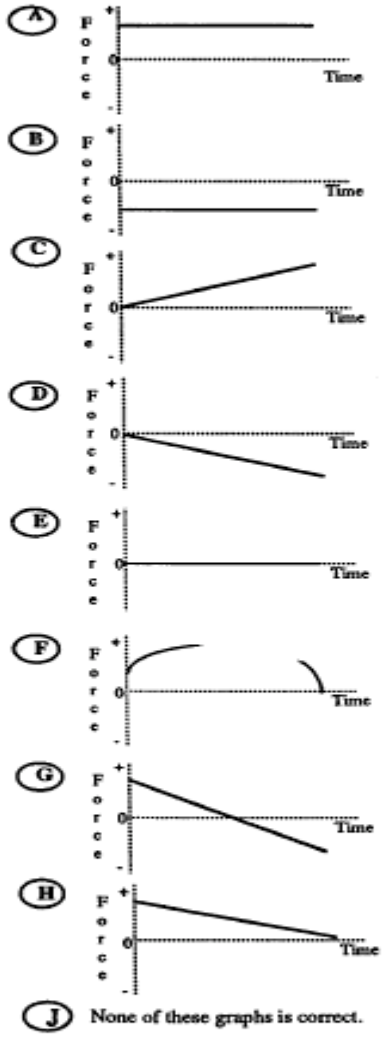
Questions 14-21 refer to a toy car which can move to the right or left along a horizontal line (the positive part of the distance axis).



Assume that friction is so small that it can he ignored.

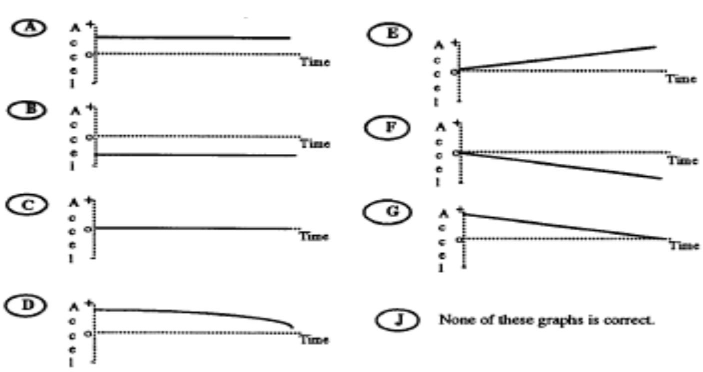
A force is applied to the car. Choose the one force graph (A through H) for each statement below which could allow the described motion of the car to continue. You may use a choice more than once or not at all. If you think that none is correct, answer choice J

14. The car moves toward the right (away from the origin) with a steady (constant) velocity.
15. The car is at rest
16. The car moves toward the right and is speeding up at a steady rate (constant acceleration).
17, The car moves toward the left (toward the origin) with a steady (constant) velocity.
18. The car moves toward the right and is slowing down at a steady rate (constant acceleration).
19. The car moves toward the left and is speeding up at a steady rate (constant acceleration).
20. The car moves toward the right, speeds up and then slows down.
21. The car was pushed toward the right and then released. Which graph describes the force after the car is released.



Questions 22-26 refer to a toy car which can move to the right or left along a horizontal line (the + distance axis). The positive direction is to the tight.

Different motions of the car are described below. Choose the letter (A to G) of the acceleration-time graph which corresponds to the motion of the car described in each statement.
You may use a choice more than once or not at all. If you think that none is correct, answer choice J.



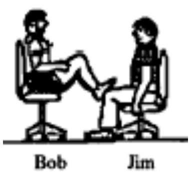
22. Tie car moves toward the right (away from the origin), speeding up at a steady rate.
23. The car moves toward the right, slowing down at a steady rate.
24. The car moves toward the left (toward the origin) at a constant velocity.

25. The car moves toward the left, speeding up at a steady rate.
26. The car moves toward the right at a constant velocity.

Questions 27-29 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (A through G) to indicate the acceleration of the coin during each of the stages of the coin's motion described below; Take up to be the positive direction. Answer choice J if you think that none is correct.
A. The acceleration is in the negative direction and constant.
B. The acceleration is in the negative direction and increasing
C. The acceleration is in the negative direction and decreasing
D. The acceleration is zero.
E. The acceleration is in the positive direction and constant.
F. The acceleration is in the positive direction and increasing
G. The acceleration is in the positive direction and decreasing

27. The coin is moving upward after it is released.
28. The coin is at its highest point
29. The coin is moving downward.

39. Two students at in identical office chairs facing each others. Bob has a mass of 95 kg, while Jim has a mass of 77 kg. Bob places his bare feet on Jim's knees, as shown to the right. Bob then suddenly pushes outward with his feet, causing both chairs to move. In this situation, while Bob's feet are in contact with Jim's knees

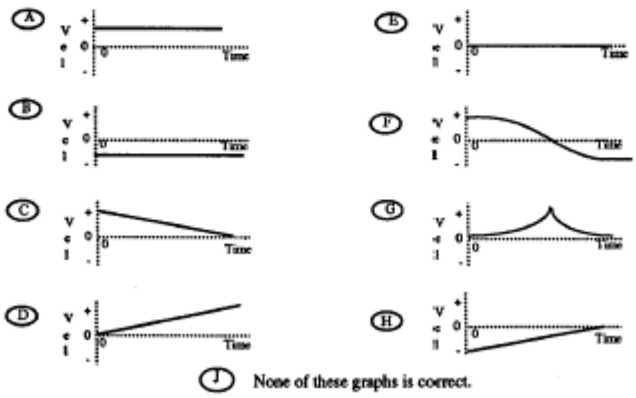


A. Neither student exerts a force on the other.
B. Bob exerts a force on Jim. But Jim doesn't exert any force on Bob.
C. Each students exerts a force an the other, but Jim exerts the larger force.
D. Each student exerts a force on the other, but Bob exerts the larger force.
E. Each student exerts the same amount of force on the other.
J. None of these answers is correct

Questions 40-43 refer to a toy car which can move to the right or left along a horizontal tine (the positive portion of the distance axis). The positive direction is to the right

Choose the correct velocity-lime graph (A - G) for each of the following questions. You may use a graph more than once or not at all. If you think that none is correct, answer choice *J.*

40. Which velocity graph shows the car moving toward the right (away from the origin) at a steady (constant) velocity?
41. Which velocity graph shows the car reversing direction?
42. Which velocity graph shows the car moving toward the left (toward the origin) at a steady (constant) velocity?
43. Which velocity graph shows the car increasing its speed at a steady (constant) rate?



A The force is toward the right and is increasing in strength (magnitude).
B. The force is toward the right and is of constant strength (magnitude).
C. The force is toward the right and is decreasing in strength (magnitude).
D. No applied force is needed
E. The force is toward the left and is decreasing in strength (magnitude).
F. The force is toward the left and is of constant strength (magnitude).
G. The force is toward the left and is increasing in strength (magnitude)

APPENDIX B: An example of demonstrations used in study