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ABSTRACT

Graphs of objects in motion are frequently used in introductory high school or college physics courses since they offer a valuable alternative to verbal and algebraic descriptions by offering students another way of manipulating the developing concepts. If graphs are to be a valuable tool for students, then the level of the students' graphing ability must be known. Microcomputer-based labs (MBL) and its use of graphs have been shown to improve content knowledge specific to graphing problems and graphing skills. The purpose of the study is to examine the relative effectiveness of the traditional lab method and MBL for engendering conceptual change in students and to investigate students' ability to interpret and use graphs to help them better learn the kinematic concepts and to apply this understanding of those concepts to new non-graphic problems. Sample populations of students enrolled in two general-level undergraduate physics course were tested. Results indicate that the MBL was more effective in engendering conceptual change in students than a traditional laboratory. Student graph interpretation skills prior to instruction, common mistakes, dominant misconceptions, instructional effectiveness, and implications for the future assessment of MBL are discussed. Contains 15 references. (LZ)

EFFECT OF MICRO-COMPUTER BASED LABORATORY ON GRAPHING INTERPRETATION SKILLS AND UNDERSTANDING OF MOTION

by

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EFFECT OF MICRO-COMPUTER BASED LABORATORY ON GRAPHING INTERPRETATION SKILLS AND UNDERSTANDING OF MOTION

One of the first topics taught in a traditional introductory high-school or college physics course is motion, including the concepts of position, velocity and acceleration. Graphs of objects in motion are frequently used since they offer a valuable alternative to verbal and algebraic description by offering students another way of manipulating the developing concepts (Arons, 1990). Graphs are the best summary of a functional relationship. Use of graphs in a laboratory setting are of critical importance for reinforcing graphing skills and developing an understanding of many topics in physics, especially motion.

If graphs are to be a valuable tool for students, then we must know the level of the students' graphing ability. Studies have identified difficulties with such graphing abilities. Students have difficulties making connections among graphs, physical concepts and the real world, and they often perceive graphs as just a picture (Linn, Layman, & Nachmias, 1987; McDermott, Rosenquist, & van Zee, 1987).

Motion labs which focus on graphing more than do the traditional labs are valuable in the investigation of student use of graphs. Computer labs, called microcomputer-based labs (MBL), provide immediately available, computer-drawn graphs of objects in motion. MBL is centered around a sonic ranger which measures the distance to an object and creates a distance-versus-time line graph of the object's motion in real-time. Learners can move and see the graph on the computer screen respond to their motion. When compared to traditional physics labs, the MBL places much more emphasis on reading and making graphs. The computer labs provide an excellent tool to explore the connection between graphing skills and learning science concepts.

Whether the students are in middle school, high school, or college, MBL has demonstrated the ability to improve their understanding of science concepts and cognitive skills such as observation and prediction (Brasell, 1987a; Thornton & Sokoloff, 1990; Friedler, Nachmias, & Linn, 1990). Students can connect abstract concepts with concrete, kinesthetic experiences. The ability of the computers to display the data graphically is cited as one of the reasons why MBL is so effective.

MBL materials appear to improve students' graphing skills (Linn, Layman & Nachmias, 1987; Mokros & Tinker, 1987; Brasell, 1987b). MBL activities seem to help students overcome difficulties with discrimination of slope and height, changes in slope and height, and matching narrative with graph features. This is particularly true of motion labs which involve the student physically moving and creating a graph.

MBL and its use of graphs have been shown to improve content knowledge specific to graphing problems and graphing skills. This investigation further explores the relationship between learning the content and graphing interpretation skills, and whether or not students can apply the new content knowledge to new problems which do not use line graphs. The ability to apply an understanding of a topic to new situations different from the situations in which the concepts were developed is a demonstration of the mastery of the concept. Two types of motion content knowledge are defined: 1) content knowledge restricted to graphing problems, and 2) more general content knowledge including word, math and picture problems. The definition of graphing skills was narrowed to interpretation skills such as calculating and interpreting slopes, and changes in slope, which are required to read motion line graphs.

Methods

Research Questions

Because the use of graphs to learn content has important classroom implications, it is important to document what the students are learning when using MBL labs and how they are learning those topics. The purpose of this study is to examine the relative effectiveness of the traditional lab method and the MBL for engendering conceptual change in students and to investigate students' ability to interpret and use graphs to help them better learn the kinematic concepts and to apply this understanding of those concepts to new non-graphic problems.

This study seeks to assess the conceptual change in the students' general graphing interpretation skills, specific kinematic graphing skills and conceptual understanding of motion as indicated by achievement on the Graphing Interpretation Skills Test (GIST) and Motion Content Test (MCT). In addition, the results from the instruments will be used to investigate students' abilities to interpret and use graphs to better learn the kinematics concepts and to apply this understanding of those concepts to new problems. The research questions to be explored are presented below.

RQ_1. Does MBL's graphic presentation improve students' ability to interpret a variety of line graphs?

RQ_2. Does MBL's graphic presentation improve students' abilities to interpret distance-time graphs, velocity-time graphs and acceleration-time graphs?

RQ_3. Does MBL's graphic presentation improve students' conceptual understanding of velocity and acceleration?

Research Question 1 (RQ_1) will be assessed using the scores on the Graphing Interpretation Skills Test (GIST). Questions from the Motion Content Test (MCT) which involve interpreting motion graphs will be used to answer RQ_2, while the remaining MCT questions will help answer RQ_3. Assessment will include an analysis of the overall averages and item analysis which will identify difficulties. To further frame the original research questions and guide the item analysis, answers were sought to specific hypothesis. By identifying the difficulties, it will be possible to provide a richer interpretation of the overall averages.

Instruments

Building on the past tests, the MCT was revised and a new instrument, GIST, was built. The GIST contained 11 multiple-choice items. Three of the items were adapted from the Test of Graphing in Science (TOGS) by McKenzie and Padilla (1986). The remaining items were written by the investigator to match the specific interpretation skills. Distractors were developed and were based on previously identified misconceptions and difficulties. In a field test, the graphing interpretation skills test (GIST) had a separation reliability of 0.97.

The MCT was constructed from several sources and consisted of two types of problems, those which focused on kinematic graphs and those which focused on more traditional non-graphing motion questions. Multiple-choice items on kinematics graphing were adapted from tests by Thornton and Sokoloff (1990) and from previous course test items. Non-graphing motion items were adapted from the Mechanics Diagnostic Test (Halloun & Hestenes, 1985a), Force Concept Inventory (Hestenes, Wells & Swackhamer, 1992) and previous course tests. Additional items were developed by the investigator based on previous research, and after consulting the course professor. The motion content test (MCT) had an average separation reliability coefficient of 0.98 (KR-20 equivalent) as a pre- and post-test in a field test. Both the GIST and MCT are included in the appendix.

Design

The nonequivalent control-group design (Campbell & Stanley, 1963) was selected. The students in one undergraduate introductory physics class, Physical Science for Elementary Teachers (Q202), used the MBL laboratories and serve as the treatment group. Another undergraduate introductory physics class, General Physics (P201), employed more traditional motion laboratories and functioned as the control group. The two courses are separate from each other and are taken by different student populations. The dependent variable will be student achievement on a motion test and a graphing interpretation skills test. The content of the lectures and laboratory activities was documented to identify differences in instruction which may affect the variables.

Sample

The sample populations consist of students enrolled in two general-level undergraduate physics courses. The two courses were offered at two different large midwestern universities located in the same state. The courses included lecture and laboratory and were required in their majors. A pilot study was conducted in the Fall of 1993, and the final data were gathered in the Spring semester of 1994.

The treatment course was Physical Science for Elementary Teachers (Q202) which is required to be taken by elementary education majors. The course is three credit hours and involves two 50-minute lectures and one three-hour lab each week. No textbook was used.

The control course was General Physics (P201). The course is taken mainly by premed, life and health science majors. The course focuses on mechanics and waves and is the first half of a 1 year sequence. The class consists of one 2 1/2-hour lecture, one discussion section and one 2-hour lab for five credits. The course text book was *Physics, Principles with Applications* by Giancoli.

The treatment group is 83% female while the control group is more evenly mixed with 53% of the students being female. While there are gender differences between the two groups, they are of the same ethnic /, predominantly Caucasian.

Data Analysis

Test means and standard deviations for GIST, and the two subscales of the MCT were determined. The effect size is a statistic for quantitatively describing how well the average student who receives the intervention performed relative to the average student who did not receive the intervention. Effect sizes are commonly used in meta-analysis but its use in educational research is becoming more popular. It is a useful statistic for assessing the practical significance of research results.

Since both groups come from different populations, the change from pre-test to post-test was used instead of the actual raw scores themselves to determine if significant change has occurred. The effect size will help answer the questions as to whether MBL's graphic presentation improve students' ability to interpret a variety of line graphs and whether MBL improves students' conceptual understanding of velocity and acceleration.

To further answer the three research questions and to provide data, individual item analysis was employed. The Statistical Analysis System (SAS) was used to construct matrices which displayed the frequency of students' responses on two different questions or on both the pre- and post-test. For each hypothesis, matrices of appropriate items were constructed to answer the hypothesis.

With the matrix method, it is possible to document whether students' difficulties or misconceptions are consistent across questions and whether there is a relationship between difficulties and misconceptions identified in one question and the way in which students answered another question. For the purposes of evaluating the effect of MBL material, this method of data presentation is superior to the simple presentation of students' percentages selecting a specific multiple-choice answer on the pre- and post-test. The matrix method allows the strength of the students' understanding of a concept to be evaluated.

The results from a matrix will be classified into one of three categories: thorough understanding, partial understanding and no evidence for understanding. When comparing two similar questions, the students who answer both questions correctly will be classified as having a thorough understanding. Students who answer one of the questions correctly but answer the second question incorrectly will be classified as having a partial understanding. Students who miss both questions demonstrate no evidence for understanding.

A sample matrix is illustrated in Figure 1. The column represent the possible choices for Q19 while the rows represent the responses for Q14. Question 19 involved calculating the slope of a line on a generic graph and Question 14 had the students determining the slope of a specific line on and graph of mass versus volume. The instrument including the questions is included in the appendix. The total for the column shows how many students selected that option for the question. Within the matrix are boxes which contain the data on how students responded on both questions. Each box contains a series of four numbers. The first is the frequency, which is a total number of students who selected the corresponding question options. The percent signifies what percentage the frequency represents of the total number of students taking the test. The column percent signifies what percentage the frequency represents of the total number of students selecting that column option. The row percent signifies what percentage the frequency represents of the total number of students selecting that row option.

The results of the matrix in Figure 1 are interpreted below as an example. The correct answer, shown in bold on the matrix, is B for Q19 and C for Q14. Sixty-four of the 134 students, or 47.76%, answered both questions correctly and have demonstrated a thorough understanding of the concept tested in the two questions. This corresponds to the frequency and the percent on the matrix. Of the 90 students who answered Q14 correctly, 71.11% (64 of the 90) of those students also answered Q19 correctly. This is labeled as the row percent. Eighty-two students answered Q19 correctly, of those, 78.05% (64 of the 82) were also successful and answered Q14 correctly. This corresponds to the column percent. Students who answer one of the questions correctly but answer the second question incorrectly have a partial understanding. Of the 90 students who answered Q14 correctly, 26 of the students missed Q19. These 26 along with the 18 students who answered Q19 correctly and Q14 incorrectly comprise those students who have a partial understanding. They account for 32.84% of the students. For the 19% of the students who miss both questions there is no evidence they have an understanding of the concept or ability.

Figure 1: Example of a Matrix Produced by SAS

Q19

Frequency / Percent / Row Pct / Col Pct	A	***B**	C	D	J	Row Total
A	6	8	0	0	9	23
	4.48	5.97	0.00	0.00	6.72	17.16%
	26.09	34.78	0.00	0.00	39.13	
	35.29	9.76	0.00	0.00	52.94	
B	2	6	2	1	2	13
	1.49	4.48	1.49	0.75	1.49	9.70%
	15.38	46.15	15.38	7.69	15.38	
	11.76	7.32	16.67	16.67	11.76	
***C**	9	**64**	8	4	5	**90**
Q14	6.72	47.76	5.97	2.99	3.73	67.16%
	10.00	71.11	8.89	4.44	5.56	
	52.94	78.05	66.67	66.67	29.41	
D	0	4	2	1	0	7
	0.00	2.99	1.49	0.75	0.00	5.22%
	0.00	57.14	28.57	14.29	0.00	
	0.00	4.88	16.67	16.67	0.00	
J	0	0	0	0	1	1
	0.00	0.00	0.00	0.00	0.75	0.75%
	0.00	0.00	0.00	0.00	100.00	
	0.00	0.00	0.00	0.00	5.88	
Column Total	17	**82**	12	6	17	N=134
	12.69%	61.19%	8.96%	4.48%	12.69%	100.00%

The data are from the Q202 Spring 1994 pre-test. The correct responses are shown in bold and the interpretation of the responses appears in the text. Based on the above matrix and additional matrices for Q202 post-test, P201 pre-test and P201 post-test, the Table 1 was constructed and is characteristic of the tables used in the study.

Table 1: Summary of matrix Q14 and Q19
(in percent)

	Pre-test			*Pos-test*		
Course	thorough	partial	none	thorough	partial	none
Q202	48	33	19	65	23	12
P201	58	31	11	76	16	8

The matrix methods will help answer each individual hypothesis. The results from each hypothesis and the effect size results will be used in the final analysis to find detailed answers to three research questions.

Results and Analysis

Graphing Interpretation Skills

The calculated effect size using the gains in the raw scores was 0.78, which is an effect size of medium strength. The control group's initial score was higher than the treatment group's but after instruction, the control group's score did not change. The treatment's score improved and, on the post-test, exceeded the control group's score. MBL was successful at improving the Q202 students' graphing interpretation abilities. Traditional instruction on motion did not improve P201 students' graphing skills. The raw score means, standard deviations (σ) for the means and the number of students (N) who took the instruments are summarized in Table 2. To further address research question 1, five hypothesis were developed for item analysis. Results from GIST were used in the item analysis and following discussion.

Table 2: Pre- and Post-test results for the GIST

	Pre-test			*Post-test*		
Course	mean	σ	N	mean	σ	N
Q202	7.9	1.6	138	9.1	1.6	136
P201	8.6	2.0	64	8.4	1.8	34

The maximum score on the GIST is 12.

MBL will improve students' ability to read and interpret curves. Students in both groups and on both the pre-test and post-test demonstrated they could successfully read and interpret graphs. Four questions from GIST, questions 11, 12, 20 and 21, were used in the analysis.

In both courses, 86-97% of the students answered the four questions correctly. MBL did not improve the students' ability to read and interpret curves since they already possessed that ability.

MBL will improve students' ability to calculate the slope of a curve. Students demonstrated they could calculate the slope of a line, but had difficulty with the concept of zero-slope. Three items, questions 14, 18 and 19, assessed students' ability and two matrices, question 14 by 19 and 14 by 18, were constructed. Both groups improved slightly on the post-test, but when including the zero-slope concept, Q202 Physical Science students showed improvement whereas the P201 General Physics students did not. The treatment group appeared to have more conceptual change occurring. In the end, about 50% of students in both groups could calculate the slope and understand the zero-slope. Both interventions improved the students' ability to calculate the slope while the treatment slightly improved the students' ability to interpret lines with zero slopes. The treatment students had a slightly more thorough understanding of calculating slopes.

MBL will improve students' ability to qualitatively interpret the slope of a curve. Two item, questions 15 and 16, were used to construct a matrix that addressed the qualitative interpretation of slopes. Approximately half of the students on the pre-test demonstrated a thorough command of qualitatively interpreting the slope. Post-test results showed the treatment improving and the control group staying the same. MBL improved students' ability to qualitatively interpret the slope.

MBL will improve students' ability to qualitatively interpret the change in slope of a curve. Students in both courses performed poorly on both the pre- and post-test. Two items, questions 17 and 22, were used to evaluate student knowledge. Q202 improved after intervention while P201 did not. Even after instruction, less than 30% in both courses demonstrated a thorough understanding of the change in slope. MBL did improve the students' ability to qualitatively interpret the change in slope with 23% of the Q202 students improving their understanding to thorough.

MBL will improve students' ability to interrelate the results of two or more graphs. One item, question 13, was used to assess how students related data on two separate graphs. The ability of interrelating the results of two graphs again showed P201 students not improving after instruction and Q202 students making slight improvements. These improvements brought the Q202 students up to the same level as the P201 students. The most frequent error made by students was not reading the scales on the graph; instead they use the relative heights of curves to determine magnitudes. MBL only slightly improved the students' ability to interrelate the results on two graphs.

RQ_1. Does MBL's graphic presentation improve students' ability to interpret a variety of line graphs? The computation of the effect size demonstrated the treatment had a practical effect on the students. This was born out in the item analysis. The Q202 students typically had initial scores lower than the P201 students, but MBL labs lead to improvements which brought the Q202 students to the same level of achievement as the P201 students. P201 students typically did not change in their understanding. Students using MBL made improvements, but the change was small. Since graphing interpretation was never overtly taught in either class, any improvement would be the result of using the skills in laboratory. Improvements are the results of students applying what they learned in a different context to new situations. Compared to traditional instruction, MBL did improve the students' ability to interpret a variety of line graphs.

Motion Graphs

The calculated effect size using the gains in the raw scores was 1.71, which is a large effect. There were 34 items which assessed the students' ability to interpret motion graphs. The Q202 students' pre-test mean was lower than the P201 students by 8%. Post-test results showed Q202 students making large gains and exceeding by almost 20% the P201 students, who made only a slight improvement. MBL was most successful at improving the students' ability to interpret motion graphs. The raw mean scores are summarized in Table 3. To address research question 2, six testable hypothesis were developed for item analysis. Results from the graphing portion of the MCT were used in the item analysis and following discussion.

Table 3: Results for the Motion Content Test; Graphing Items

	Pre-test			*Post-test*		
Course	mean	σ	N	mean	σ	N
Q202	11.5	3.8	138	24.4	6.1	136
P201	14.2	4.5	64	17.7	5.5	34

The maximum score on the graphing portion of the MCT was 34.

MBL will improve students' ability to determine the direction of motion from a motion graph. Students started off not understanding how to interpret direction from motion graphs. Questions 27, 32, 33, 35, 52, 54, 56, 71 and 74 were used in the assessment. Matrices of 32 by 33, 52 by 54, 52 by 56 and 71 by 74 were constructed. The control group was more successful with distance-graphs on the pre-test, but with velocity and acceleration-time graphs, both group's performances were nearly the same. The students had more difficulty with motion toward the origin than motion away from the origin. Acceleration graphs were the most difficult to interpret. Post-test results show dramatic improvement in the treatment group. The treatment group scores all surpassed the control groups, with sometimes 30% more of the Q202 students than P201 having a thorough understanding of the direction. The control group scores did improve, but the gain was small compared to the treatment groups gains. MBL significantly improved the students' ability to determine the direction of motion from a motion graph.

MBL will improve students' ability to determine the magnitude of velocity from a motion graph. Questions 62, 63, 67, 68, and 76 were used. Pre-test results showed 25% of the students used height of curve as the criteria for determining the magnitude of the velocity from a distance-graph. Both groups improved on the post-test, but Q202 made a more significant gain and surpassed the P201 students. In both groups about 78% of the students were able to determine the magnitude of the velocity by calculating the slope after instruction. The same was true of determining the magnitude from a velocity-time graph. On the post-test, most of the P201 students continued to assume the sign on the graph indicated magnitude and not direction. MBL improved the students' ability to determine the magnitude of velocity from a motion graph.

MBL will improve students' ability to determine the magnitude of acceleration from a motion graph. Determining the magnitude of the acceleration was a more difficult task for the students than determining the velocity. Three test questions: 26, 69, and 70, were used. Q202 students demonstrated more difficulties on the pre-test than P201 students. They made sign errors more often and based their answers on their beliefs and not the available data. Terminology also played a role, students were more successful when the phrase "change in velocity" was used. The treatment group again made larger gains on the post-test than the control group. These gains helped approximately the same percentage of Q202 students as P201 reach a thorough understanding. MBL improved the students' ability to determine the magnitude of acceleration from motion graphs.

MBL will improve the students' ability to qualitatively interpret distance-time graph curves. The ability of students to interpret distance-time graphs was assessed using a series of questions; 31, 32, 33, 34, 35, and 36. P201 students were more successful in interpreting distance-time graphs on the pre-test. On the post-test the treatment group surpassed the P201 students, with typically 20% more students having a thorough understanding on any one question. Common difficulties on the pre-test included not being able to determine direction, interpreting velocity, and interpreting acceleration from distance-time graphs. Post-test results showed 90% of the Q202 students had a thorough understanding of distance-time graphs. MBL significantly improved the students' ability to qualitatively interpret distance-time graphs.

MBL will improve the students' ability to qualitatively interpret velocity-time graph curves. Students ability was evaluated using a series of questions; 52, 53, 54, 55, 56, 57 and 58. Initially, both populations of students answered velocity-time graphs questions in similar fashions and approximately the same percentages having partial and thorough understandings. The most common error involved using position criteria when interpreting velocity-time graphs. Post-test results showed a significant improvement in the Q202 scores with approximately 80% of the students having a thorough understanding of velocity-time graphs. P201 students also made gains, typically improving by 20% or more. MBL significantly improved the students' ability to qualitatively interpret velocity-time graphs.

MBL will improve the students' ability to qualitatively interpret acceleration-time graph curves. Both populations of students did poorly on acceleration-time graphs with less than 10% having a thorough understanding on the pre-test. Five questions were used in the assessment: 71, 72, 73, 74, and 75. Students used velocity-graph criteria to solve acceleration graph questions. Approximately half of the students selected a velocity analog, and another 20% selected a distance analog. The errors were further complicated by a lack of understanding of sign and an inability to interpret "speeding up at a steady rate." Post-test results demonstrated little improvement for the control group but more significant improvement for the treatment. Less than 15% of the P201 students had a thorough understanding compared to approximately 57% of the Q202 students. MBL significantly improved the students' ability to qualitatively interpret acceleration-time graphs.

RQ_2. Does MBL's graphic presentation improve students' ability to interpret distance-time graphs, velocity-time graphs and acceleration-time graphs? The effect size shows MBL made the largest impact on students' ability to interpret motion graphs. This is an expected result since the treatment group spent much of its lab time working with motion graphs. The item analysis further enforces the gains made by the treatment group. Both groups had similar difficulties, and the treatment was more effective at addressing the difficulties and overcoming the problems. MBL significantly improved the students' ability to interpret distance-time, velocity-time and acceleration-time graphs.

Conceptual Understanding of Motion

The calculated effect size using the gains in the raw scores was 0.88. The control group's initial raw score mean was higher than the treatment group's and did improve slightly on the post-test. The treatment's score improved more significantly on the post-test. MBL was successful at improving the students' conceptual understanding of motion as measured by non-graphing questions. The raw score means, standard deviations (σ) of the means and number of students (N) are summarized in Table 4. To further address research question 3, four testable hypothesis were developed for item analysis. Results from the non-graphing portion of the MCT were used in the item analysis and following discussion..

Table 4: Test Results for the Motion Content Test; Non-graphing

	Pre-test			*Post-test*		
Course	mean	σ	N	mean	σ	N
Q202	9.8	2.4	138	13.6	3.7	136
P201	13.4	3.9	64	14.3	3.3	34

The maximum score on the non-graphing MCT test is 22.

MBL will improve students' ability to differentiate between position and velocity. If students' understanding of position and velocity are undifferentiated, then it should be possible to detect their confusion by analysis of a matrix of question 43 and 44. P201 students did significantly better on the pre-test being able to differentiate between position and velocity. On the pre-test, 27% of the Q202 used a distance-analog to answer both questions. Q202 students did make significant gains on the post-test, but P201 students still had a more thorough understanding and fewer of the students used a distance-analog. The significant improvement by the Q202 students demonstrated that MBL does improve the students' ability to differentiate between position and velocity.

MBL will improve students' ability to differentiate between velocity and acceleration. A matrix of question 43 by 45 and question 49 by 50 detected students' understanding of velocity and acceleration. The difference between populations was very large with the Q202 students more likely to confuse velocity and acceleration. The difference might be due to the P201 lecture bias. The instructor's lecture before the pre-test included some of the topics covered on the pre-test. Approximately 70% of the Q202 students used velocity criteria to answer acceleration questions. Post-test results show no change for P201 students and sizable gains for the Q202 students. Even with the large gains for the Q202 students on the post-test, over 20% more of the P201 students had a thorough understanding of the concepts. Acceleration is the most difficult concept for the students; even after instruction, less than 60% of the students in either class have a thorough understanding of the concept. MBL did improve the students' ability to differentiate between velocity and acceleration.

MBL will improve students' ability to solve simple quantitative problems. Two simple quantitative problems were presented. Q202 students were more capable at answering simple quantitative questions prior to instruction than P201 students. After instruction, both groups improved with P201 slightly improving more, which is to be expected from a course which emphasized quantitative understanding. Instruction in both cases improved ability to solve quantitative problems. MBL improved the students' ability to solve simple quantitative problems, but similar gains were also achieved with traditional instruction.

MBL will improve students' ability to solve picture problems. Questions 60 and 65 and a matrix of questions 59 and 60 were used in the assessment. The students on the pre-test were not successful with picture problems, with less than 30% in either class demonstrating a thorough understanding. The post-test results showed approximately equal gains for both groups. MBL did improve the students' ability to solve picture problems, but the same gain was also achieved from traditional instruction.

RQ_3. Does MBL's graphic presentation improve students' conceptual understanding of velocity and acceleration? The effect size demonstrated the treatment had a practical affect on the students. The treatment students made gains in their abilities to differentiate between concepts and in their ability to solve quantitative and picture problems. The gains they made were typically larger than the gains made by the control group although more P201 students started and finished with a thorough understanding of the topics. The Q202 students learned the content within the context of motion graphs and were able to apply it to non-graphing problems. The P201 students were not able to apply their knowledge to graphing problems. Through out the MCT and GIST, the Q202 group appears to be making more conceptual changes than the P201 students. MBL improved the students' conceptual understanding of velocity and acceleration.

Conclusion

This study sought to explore what the students were learning and how well they mastered those concepts. In addition, the study sought to identify what the students knew prior to instruction. Knowing what the students bring to the classroom helps the instructor better address the students' knowledge and elicit conceptual change, bringing the students' beliefs closer to the accepted scientific explanations.

The results on the Graphing Interpretation Skills Test and Motion Content Test indicated significant differences between a traditional laboratory and microcomputer-based laboratory. MBL was more effective at engendering conceptual change in students. The results were determined by computing effect sizes and by item analysis. The multiple-choice instruments had high reliability.

The control group and treatment group came from significantly different populations of students. The P201 students consistently outperformed the Q202 students on the pre-test. Students entering Q202 demonstrated more difficulties and held more misconceptions than did the students entering P201 despite the fact more Q202 students had high school physics course work. Other factors contributed to the P201 students' initial success, including more college science and mathematics courses and how the students perceived their need for the course materials. Because there were significant differences between the students on the pre-test, the use of gain scores corrects for the initial differences.

An additional goal of this study was to identify what the students know when they enter the physics classroom. Although common misconceptions have been identified and appear consistent across differing populations, the results from this study are specific to the populations studied and should not be considered generalizable to different populations.

The students in both groups entered the study being able to read and interpret a variety of line graphs. Understanding the change of slope remained the most difficult skill for the students, which is not unexpected since they probably have never had to interpret this before. Only about on-half of the students were able to calculate a slope and interpret a zero-slope curve. This is a disappointing result for such a basic graphing skill. The ability to work with the slope is a significant skill for the students to master in order to facilitate interpreting motion graphs. Instructors can not assume the students will completely understand how to calculate and interpret the slope. MBL provides an excellent medium for helping students develop a more thorough understanding of how to calculate the slope and how to interpret its meaning. Activities which involved slope should be built into the motion labs so that the students will gain experience with the skill. Students should be expected to understand how to determine the slope and how to apply this specifically to motion after instruction.

Students will probably have never experienced motion graphs prior to using MBL labs. When they first encounter these graphs, they can rely on either their graphing interpretation skills or their own preconceptions. It appears that students resort to their own preconceptions before they attempt to use their graphing interpretation skills to determine an answer. This might be the result of a multiple-choice test in the study, a format which is typically used to measure the students' ability to memorize facts. The students might also choose the answer which requires the least amount of effort. On a test where time is a limiting factor, it is more likely the student will resort to memorized facts or their own preconceptions than to take the time and figure out an answer. These limitations influence the pre-test motion graph results and would yield scores which are lower than the students' actual abilities.

The biggest difficulty encountered by the students was interpreting the direction of motion from a motion graph. This affects their success in interpreting the results of all motion graphs. Students find motion toward the origin especially difficult. Perhaps motion away from the origin is easier for the students because the reference point is also the location where the motion began. The students do not have to change their reference frame. On a distance-time graph, the motion away is an additive process with increasing distance from the same spot where the motion began. This may be easier for the students than moving toward the origin, involving distances from the origin getting smaller even though you are getting further from the starting point. Motion toward requires the students to change their frame of reference which is a difficult task without prior experience. MBL labs must provide the students with experiences predicting and interpreting direction on a variety of motion graphs. As demonstrated by the successful Q202 laboratories, experiences should include motion away from the origin to provide the students with an anchoring concept, something they are familiar and successful with. An understanding of motion toward the origin can be built upon their understanding of motion away from the origin.

Beyond determining direction, the students often confused types of graphs, perhaps reflecting their confusion of the associated concepts. In addition, the students must have an opportunity to explore the differences and the relationships among the various motion graphs. They need to create distance-time, velocity-time and acceleration-time graphs of the same motion and discuss the differences between the graphs. As the students learn to differentiate between the graphs, they will begin to develop a more precise definition of the concepts and will be able to better differentiate the concepts. Numerous examples are needed in order to provide the student with sufficient experience and examples.

The dominant misconception the students bring to the classroom is undifferentiated understandings of the concepts of position, velocity and acceleration. Scientists have precise definitions of these concepts which they can apply to numerous situations. Students have had a variety of experiences in which they have built up their understanding of the concepts. Since they probably have never had a formal course in physics, their understanding consists of overlapping, misinterpreted pseudo-definitions which may work in a few specific instances but are not generalizable. Formal instruction will hopefully provide the students with a scheme for understanding their experiences and narrowing their definitions of the concepts. MBL provides an excellent environment in which to address the students' misconceptions. The students can test their own theories and the proposed scientific theory with quick, easily understood graphs.

Challenging the students' understanding does not guarantee that conceptual change will occur. When faced with a discrepancy, students can change their own beliefs, rationalize the data away or they can become apathetic. Indeed, in lab, students would ask the instructor if they "should write down the correct answer or what the graph said," thereby attempting to rationalize away the data and maintain their current beliefs. While MBL is a powerful tool for conceptual change, it must be accompanied by other factors which will encourage the students to challenge their beliefs and to begin to change their own concepts. Factors might include motivation, interest and relevancy for the student. Identifying those factors will be a significant research topic to pursue.

The study showed that the Q202 students learned more about graphing interpretation skills, more about motion graphs and more about conceptual understanding of motion, than did the P201 students. That learning was made possible by the effective use of MBL activities. While the P201 students spent less time on motion, it can and should be argued that if the students would gain as much as the Q202 students, then it would be to their advantage to devote more time to the basic concepts. Q202 took advantage of the learning environment and instructional possibilities made possible by MBL. As demonstrated by the Q202 lab materials, to effectively use that time, MBL activities designed to elicit conceptual change should be incorporated into introductory physics courses.

Significance

The analysis of the results indicate the superiority of MBL activities over traditional laboratory methods for instruction on motion. Incorporation of MBL activities is, therefore, recommended for instruction. The effectiveness of MBL depends on the extent to which it is employed and the nature of the activities. Activities which emphasis qualitative understanding, requiring written explanations, cooperative learning, eliciting and addressing students' prior knowledge and employing the learning cycle are more effective for engendering conceptual change. The lab activities in Q202 are well designed and effective at causing conceptual change.

Students' "naive knowledge" tends to be resilient and resistant to change as noted by the several researchers (e.g., Clement, 1982; Halloun & Hestenes, 1985b). It is natural that any desired change of the existing knowledge will require a reasonable period of time. In addition, MBL labs may be unfamiliar to the students. Consequently, the students may require a longer period of time to become acquainted with the software and the characteristics of the activities which will benefit them. The use of MBL for additional topics in physics and a treatment period of at least three weeks is suggested to allow adequate time for the effects of MBL to develop.

For the future assessment of MBL, new instruments need to be employed. MCT and GIST should be revised to further explore the student understandings. In addition, supplemental interviews should be conducted immediately following the tests to elaborate on the students' understanding. More items should be incorporated into the GIST to further define and explore the students' mastery of specific subskills. A more diverse selection of motion content questions, including more difficult quantitative questions, need to be added to the MCT.

The effects of gender, achievement on the pre-test graphing in erpretation skills, high school physics courses, college science and math course and math/science anxiety on student achievement in MBL labs should be assessed. These possible effects were not addressed in this study because of small number of male subjects and time constraints. The results might have important implications. Perhaps students with low pre-test graphing interpretation skills scores will do more poorly since they need to master the basic graphing interpretation skills before the motion concepts can be learned. The data from this study coul l be analyzed and used as pilot data o investigate these topics.

In addition to these areas, an important consideration which is not commonly in estigated is how students respond to a discrepant event. An instrument to assess the students' responses should be developed and tested. MBL can elicit conceptual chang in many of the students, but only if they are willing to change. It is a significant research question to identify charac istics which will enable the student to give up rationalizations and apathy, and to change their conceptual frameworks. With an understanding of how to make students comfortable with challenging their beliefs, better instruction and activities could be designed and implemented.

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NAME:______________________ ID NUMBER:______________

Directions: Fill in your name and ID number on the bubble sheet. Questions 1 and 2 are optional. If you choose not to answer them, then leave those spaces blank on the answer sheet and start with question 3. Choose the **one best** response to each question.

OPTIONAL

1. Gender: a. Male b. Female
2. Ethnicity: a. African-American b. Asian c. Hispanic d. White e. Other

REQUIRED

3. What is the number of semesters of science you completed between 9th and 12th grades?
a. 0 b. 1 c. 2 d. 3 e. 4 F. 5 G. 6 h. 7 i. 8 j. more than 8

4. What is the number of semesters of math you completed between 9th and 12th grades?
a. 0 b. 1 c. 2 d. 3 e. 4 F. 5 G. 6 h. 7 i. 8 j. more than 8

5. What is the number of semesters of physics completed between 9th and 12th grades?
a. 0 b. 1 c. 2 d. 3 e. 4 F. 5 G. 6 h. 7 i. 8 j. more than 8

6. What is the number of credit hours of completed science college courses?
a. 0-2 b. 3-5 c. 6-8 d. 9-11 e. 12-14 j. more than 15

7. What is the number of credit hours of completed math college courses?
a. 0-2 b. 3-5 c. 6-8 d. 9-11 e. 12-14 j. more than 15

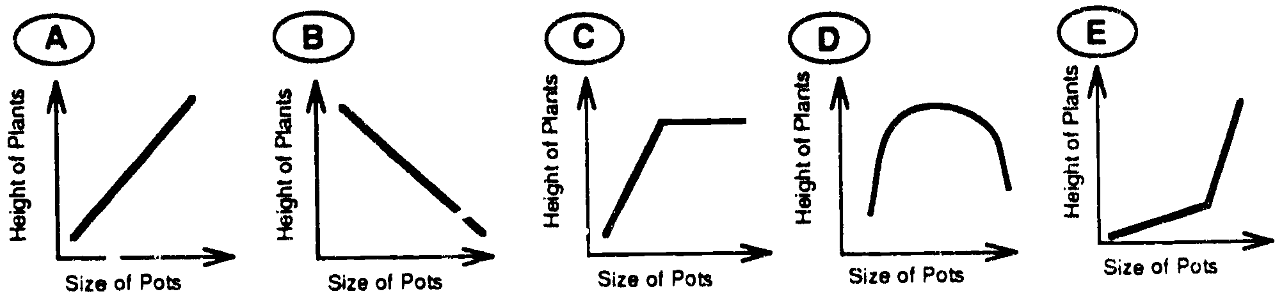
8. At what level would you place your graphing skills?
a. excellent b. above average c. average d. below average e. poor

9. How comfortable are you with physics?
a. excellent b. above average c. average d. below average e. poor

10. At what leve would you place your physics knowledge?
a. excellent b. above average c. average d. below average e. poor

Graphing Interpretation Skills Test (GIST)

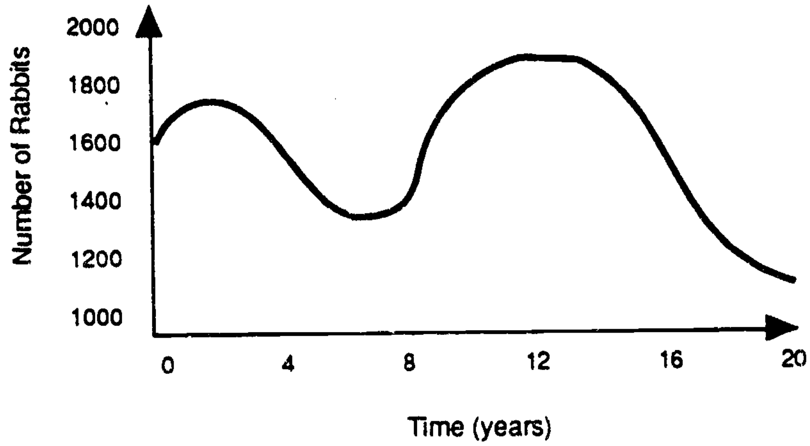
•Zach plans to study how well sunflowers grow in different size pots. The graph below show four possible outcomes of his experiment. Which graph is **best** described by the following statements:

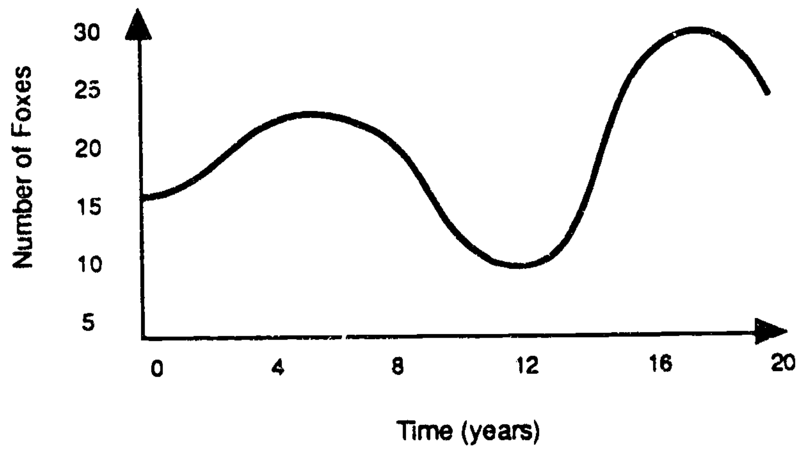


11. As the pot sizes increase, the plant height goes down.

12. As the pot size increases, the plant height increases up to a certain pot size. With larger pots, plant height remains the same.

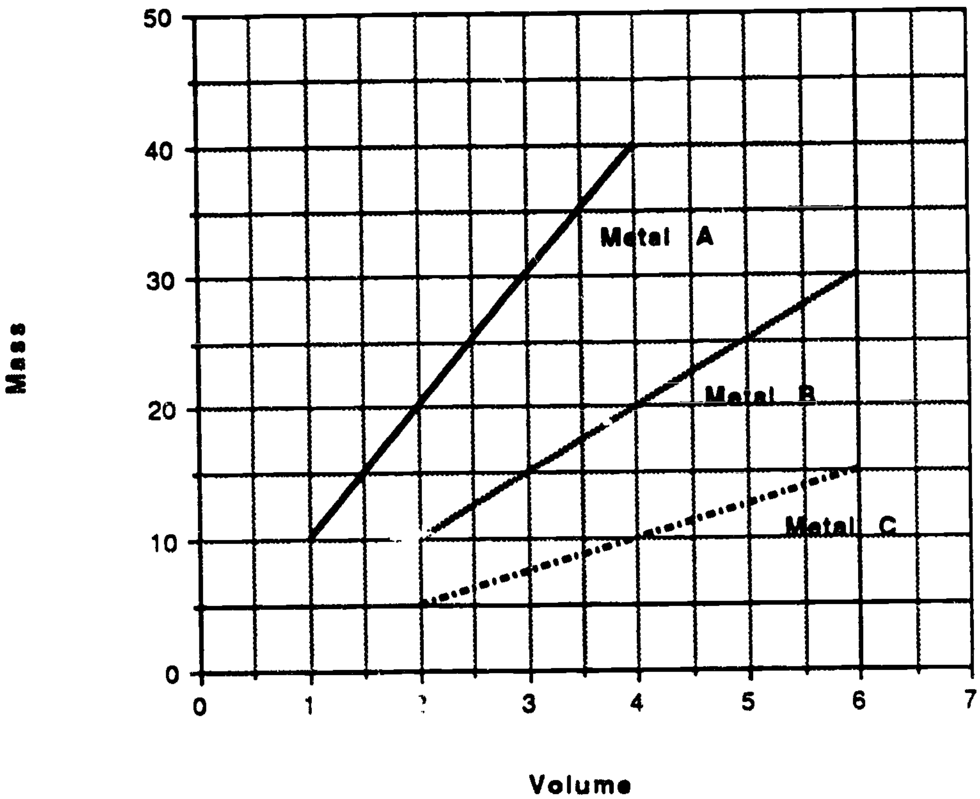
•A scientist was interested in the number of foxes and rabbits living in a valley. She counted their numbers many times over twenty years. A copy of her graphed results is shown below.





13. Which of these statements is supported by the **two** graphs?
    a. The number of rabbits and foxes increase at the same time.
    b. During the 6th year there are more foxes in the area than rabbits.
    c. There were the greatest number of foxes and the fewest rabbits at the 6th year point.
    d. An increase in the number of rabbits is followed within a few years by an increase in the number of foxes.

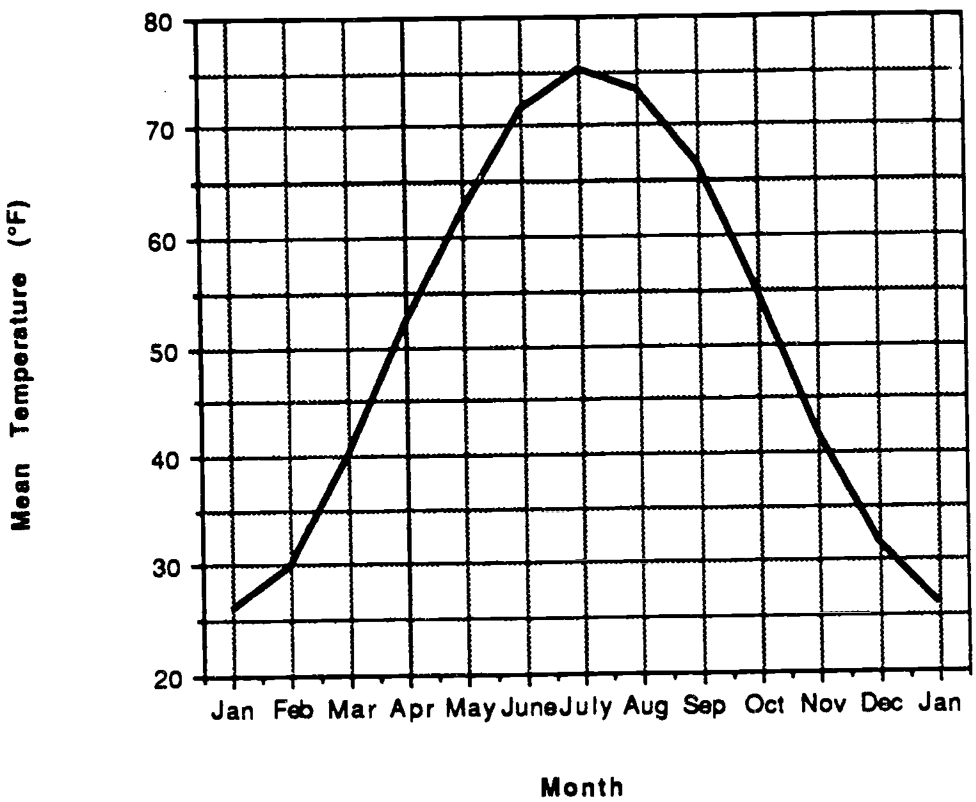
•The density of a metal is the ratio of mass divided by volume. An experiment was set up to measure the density of three metals. For several different masses of the same metal, the volume it occupied was measured. These were plotted on the graph below.



14. What is the slope for the line for Metal A?
    a. 0.10
    b. 3.0
    c. 10.0
    d. 30.0

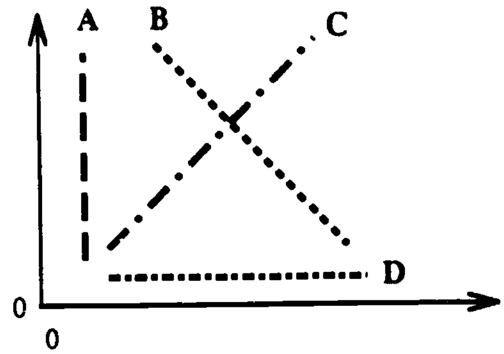
15. Which metal has the smallest density?
    a. metal A
    b. metal B
    c. metal C
    d. all the same

•The following graph shows the change in the monthly mean temperature for Indianapolis for a year. Answer the following questions about the graph.

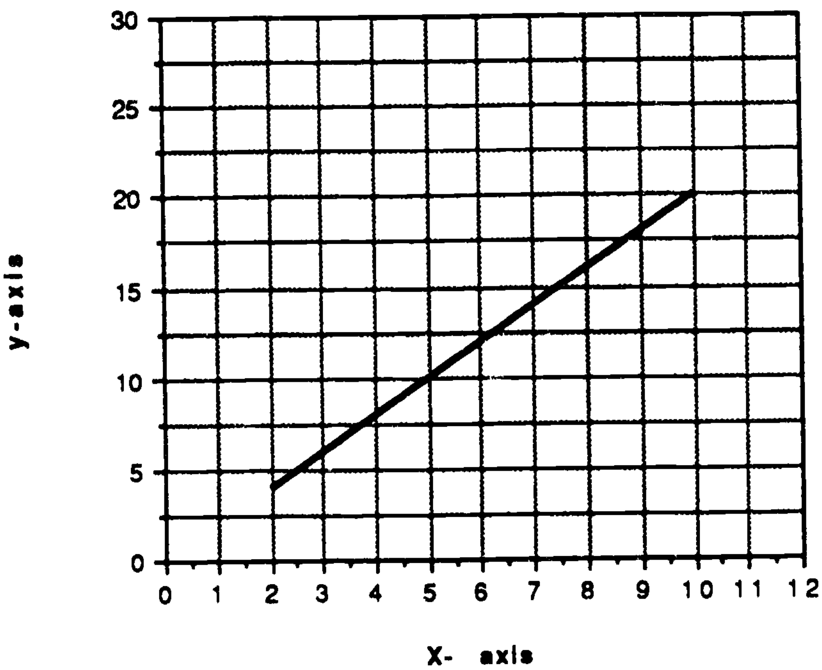


16. During what time interval was the largest temperature change?
    a. Jan to Feb
    b. Apr to May
    c. June to July
    d. July to Aug
    j. none is correct

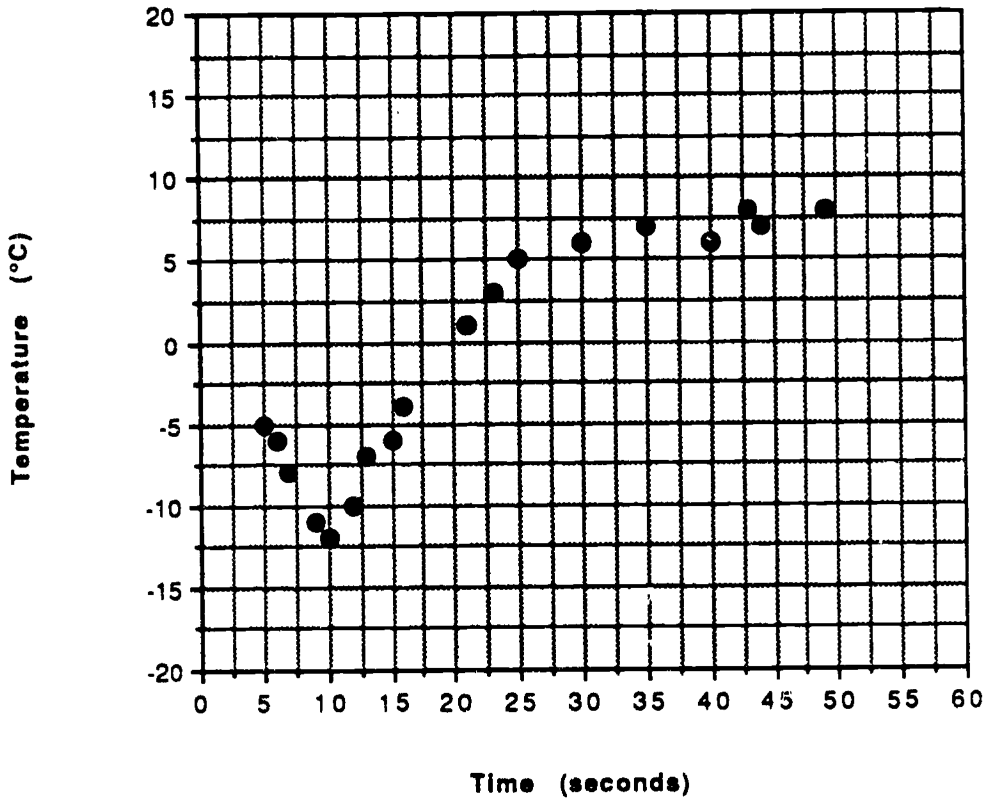
17. During what interval was the rate of the temperature change most nearly constant?
    a. Jan to Mar
    b. Mar to May
    c. June to Aug
    d. July to Sept
    j. none is correct



18. Which line in the graph above has a slope of zero?
    a. A
    b. B
    c. C
    d. D
    e. A and D
    j. none is correct



19. Calculate the slope for the graph above.
    a. 0.5
    b. 2.0
    c. 8.0
    d. 16.0
    j. none is correct

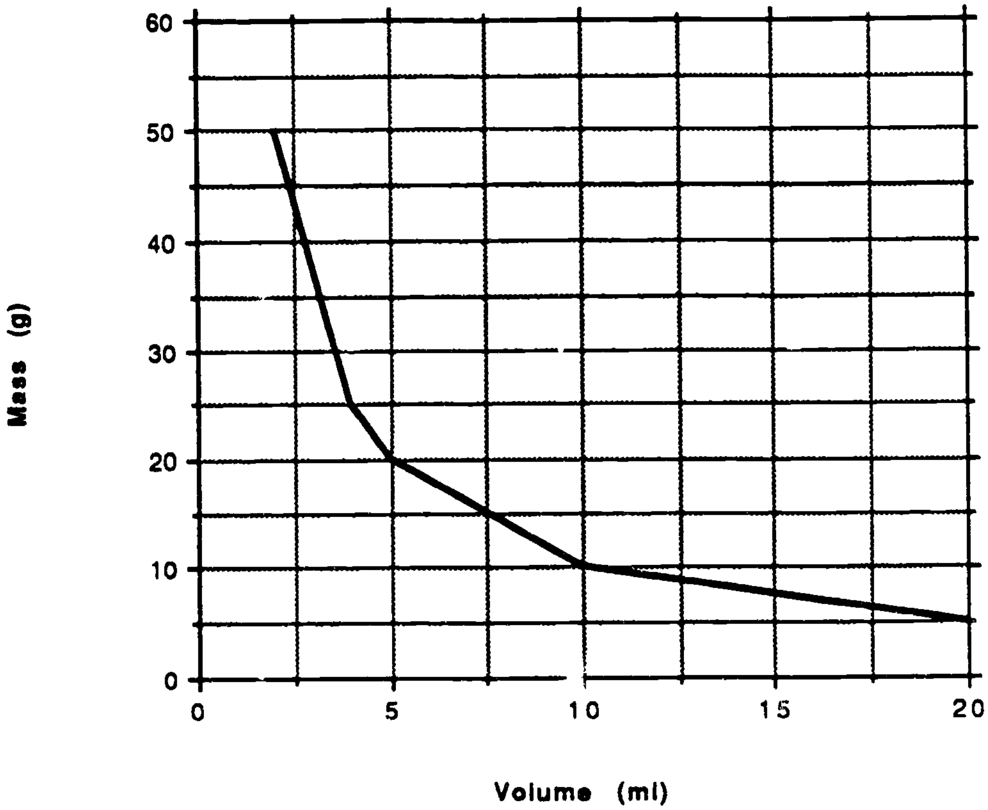


20. What was the coldest temperature?
   a. -15
   b. -12
   c. -5
   d. 0
   e. 8

21. What was the temperature at time = 19 seconds
   a. -5
   b. 0
   c. 5
   d. 20

32

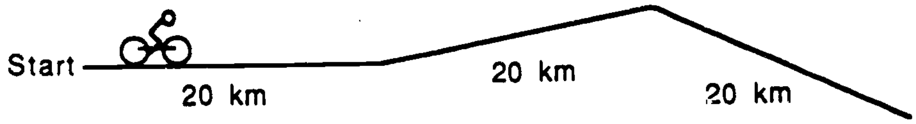
•The following graph shows the relationship between the mass and volume of a gas. Answer the following question about the graph.



22. If you were to increase the volume by 2 ml, where would you expect the largest change in mass.
    a. around 40 g
    b. around 20 g
    c. around 15 g
    d. around 7.5 g
    j. none of the options is correct

Motion Content Test (MCT)

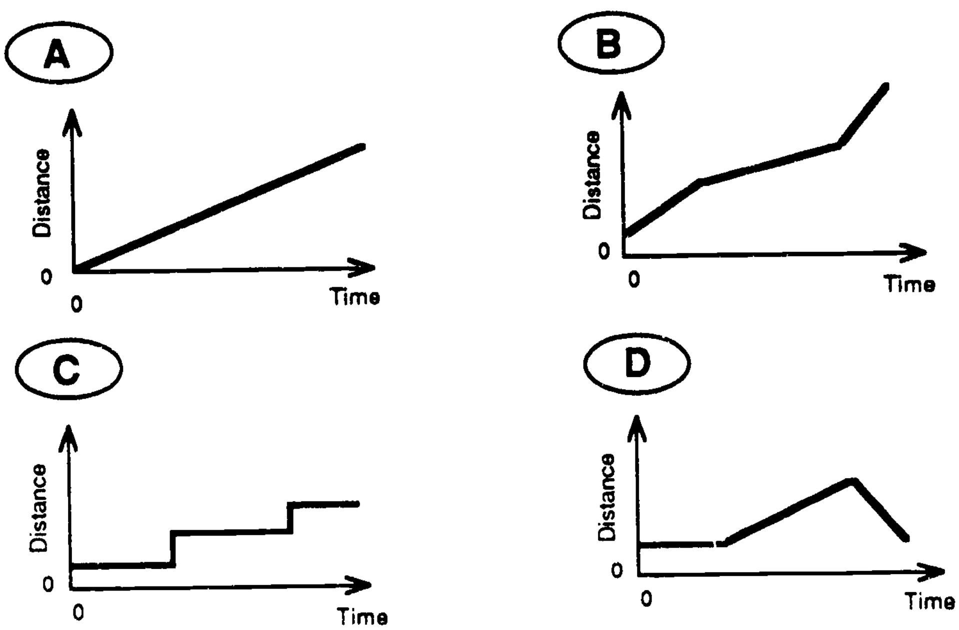
• A bicyclist leaves town. Lisa travels 20 kilometers in 30 minutes at a constant speed. The next 20 kilometers is up hill, which requires 45 minutes to travel at a constant speed. The last 20 kilometers is downhill, which requires 15 minutes to travel at a constant speed. The starting point is the origin. <u>If you think that none of the options is correct, answer</u> J.



23. What is the speed of the cyclist as she travels uphill?
    - a. 40.00 km/hr
    - b. 26.67 km/hr
    - c. 80.00 km/hr
    - d. 48.89 km/hr
    - j. none is correct

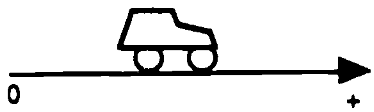
24. What is the average speed of the cyclist for the entire trip?
    - a. 40.00 km/hr
    - b. 26.67 km/hr
    - c. 80.00 km/hr
    - d. 48.89 km/hr
    - j. none is correct

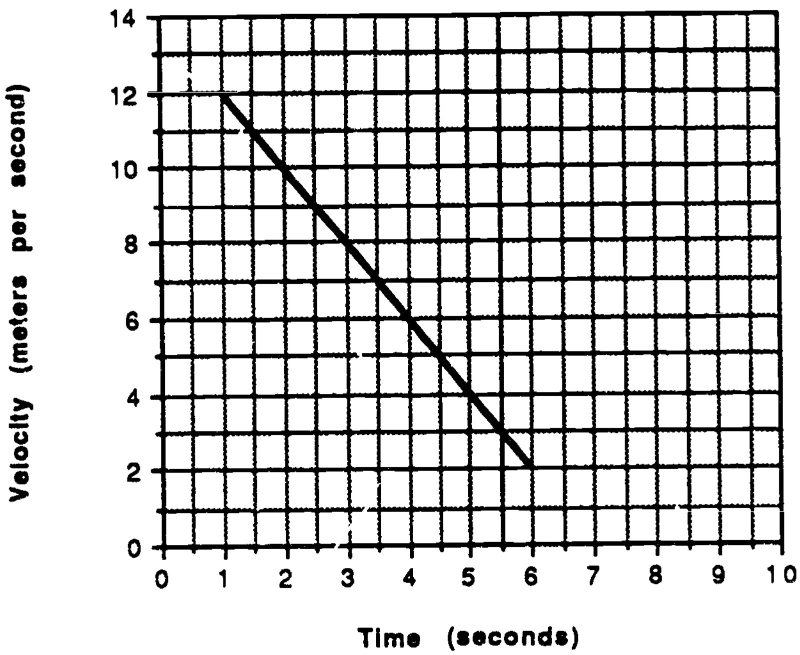
25. Which graph represents the distance-time graph of the cyclist's motion?



J . None is Correct

•A car can move on a straight-line path. Given the following velocity-time graph, determine the acceleration of the object. <u>If you think that none of the options is correct, answer</u> J.



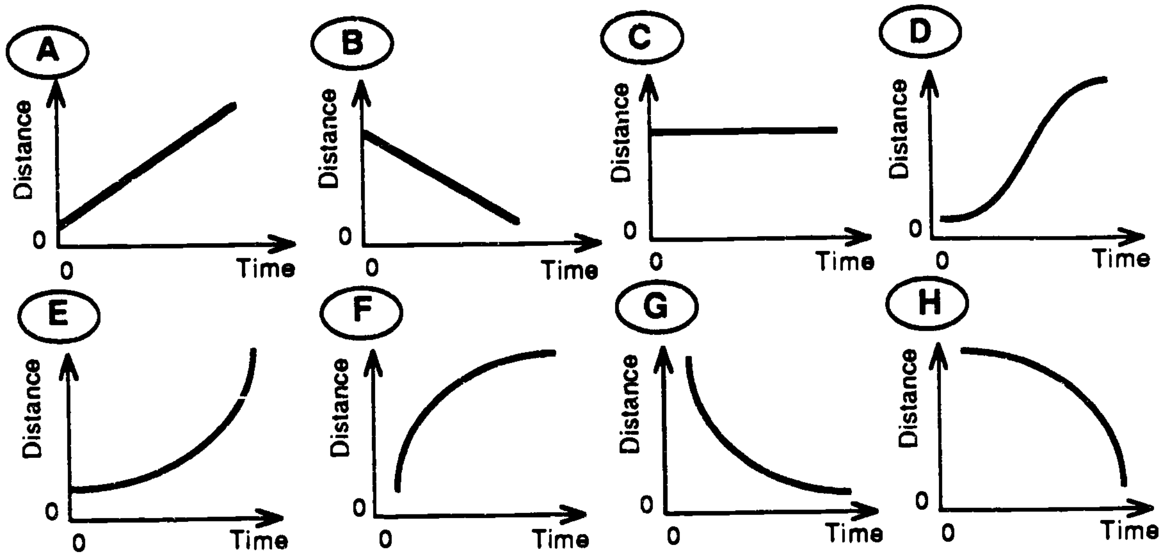


26. What is the acceleration of the object?
    a. - 5 meters/second^2
    b. - 2 meters/second^2
    c. - 0.5 meters/second^2
    d. 0.5 meters/second^2
    e. 2 meters/second^2
    f. 5 meters/second^2
    j. none of the options is correct

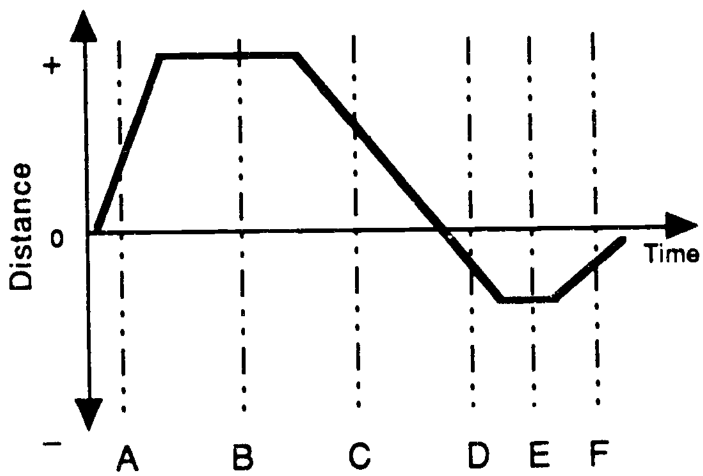
27. What is the direction of the motion?
    a. toward the origin
    b. away from the origin
    c. unable to determine the direction
    d. not moving
    j. none of options is correct

28. What is happening to the object according to the velocity-time graph above?
    a. The object is speeding up.
    b. The object is slowing down.
    c. The object is travelling with constant speed.
    d. The object is not moving.
    j. Unable to tell.

29. Which distance-time graph describes the motion of the object from the velocity-time graph on the previous page?



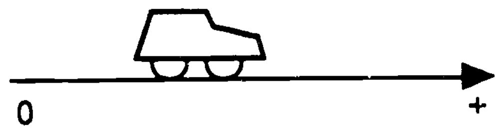
• For the following question, select the number which best answers the question.



30. At which two times is the speed of the car the same?
   a. A and C
   b. A and D
   c. C and D
   d. C and F
   e. D and F

31. At what time is the car farthest from its starting point?
   a. A
   b. B
   c. C
   d. D
   e. E
   f. F

•Choose the correct description of motion for the given distance (position)-time graph. The questions refer to a toy car which can move right or left along a horizontal line with the origin at the left and the + distance to the right. You may use a description more than once or not at all. <u>If you think that none of the options is correct, answer</u> J.



a. An object moving in a direction toward the origin with a steady (constant) velocity.

b. An object moving in a direction away from the origin with a steady (constant) velocity.

c. An object with a decreasing change of distance with increasing time.

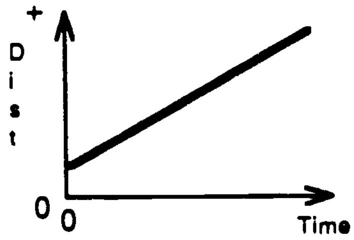
d. An object reversing direction.

e. An object moving in a direction away from the origin increasing its speed.

f. An object standing still.

i. None is correct.

32



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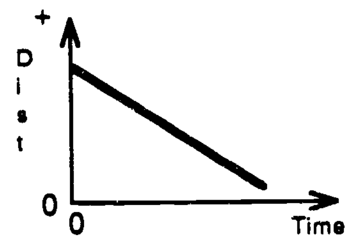

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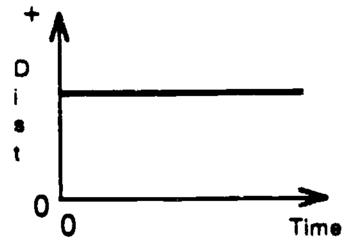

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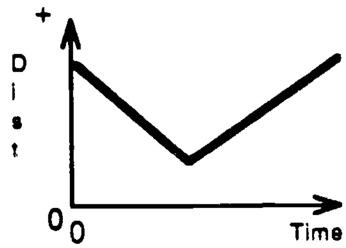

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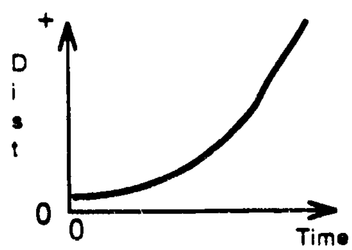


• A ball is thrown straight up, reaches its highest point and then falls to the floor. Note that each question refers to three different segments of the ball's motion: on the way up after leaving the hand, at its highest point, and on the way back down. The floor is considered the origin; up is the positive direction. The distance, velocity and acceleration of an object can be characterized by a sign (+ or -), a number and a unit.

The **sign** which characterizes the **velocity** when:

37. the ball travels downward is ____
38. the ball travels upward is ____
39. the ball is at highest point is ____

a. positive
b. zero
c. negative

The **sign** which corresponds to the **acceleration** when:

40. the ball travels downward is ____
41. the ball travels upward is ____
42. the ball is at its highest point is____

a. positive
b. zero
c. negative

The **number** which characterizes the ball's **velocity** when:

43. the ball travels downward____
44. the ball travels upward ____

a. gets larger
b. is constant and equal to zero
c. is constant and not equal to zero
d. gets smaller

The **number** which characterizes the ball's **acceleration** when:

45. the ball travels downward____
46. the ball travels upward____

a. gets larger
b. is constant and equal to zero
c. is constant and not equal to zero
d. gets smaller

As the ball:

47. travels downward, it____
48. travels upward, it____

a. speeds up
b. has a constant speed of zero
c. has a constant speed which is not zero
d. slows down

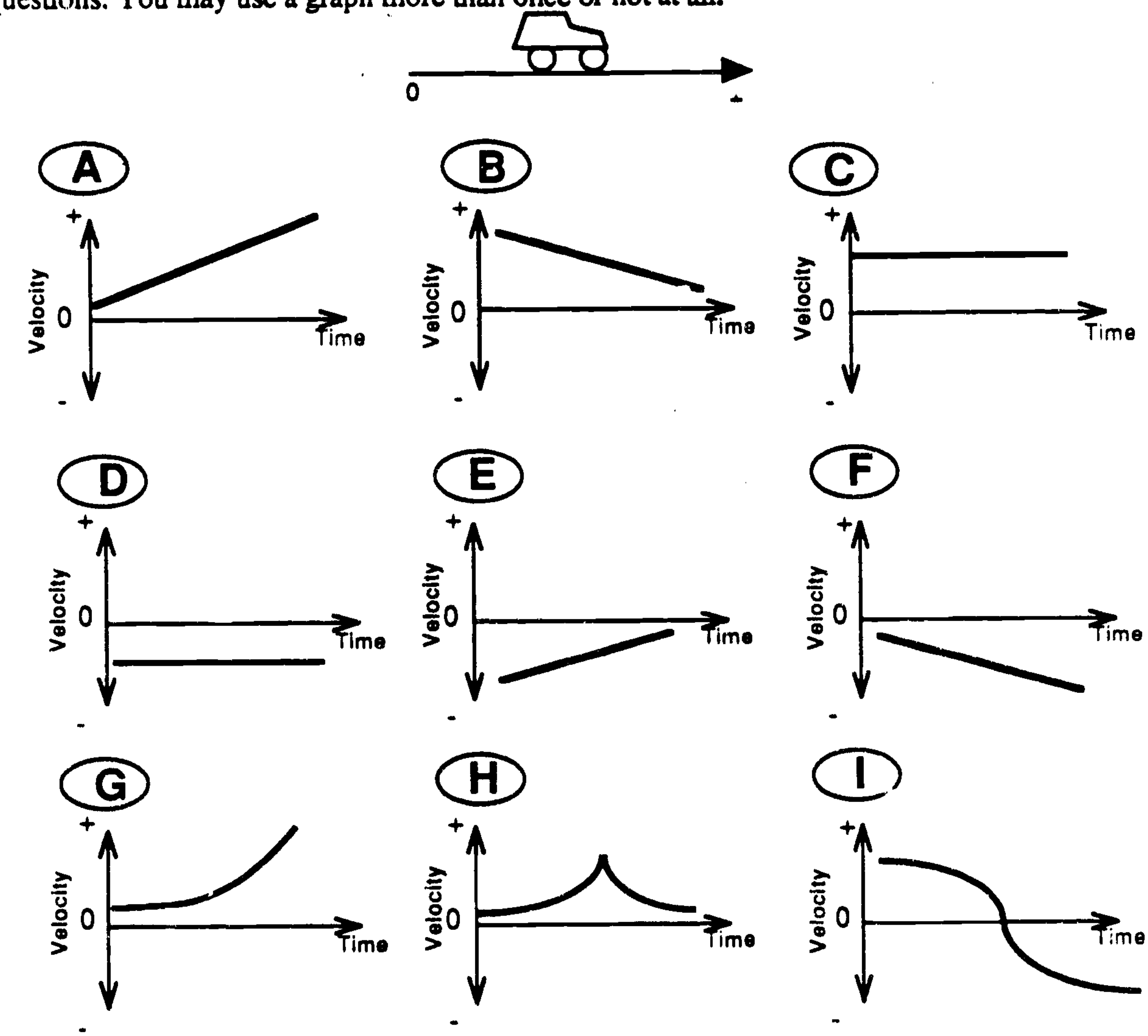
At the instant when the ball is at its highest point:

49. the velocity is____
50. the acceleration is____

a. positive
b. zero
c. negative

51. After leaving your hand and on its way up, what forces act on the ball? (Ignore air resistence)
   a. Its weight, vertically downward.
   b. A force that maintains its motion, vertically upward.
   c. A downward weight and a constant upward force.
   d. A downward weight and a decreasing upward force.
   e. An upward force, first acting alone on the ball to a certain point beyond which the downward weight starts acting on the ball.

•An object can move in either direction along a horizontal line with the origin at the left and the + distance axis to the right. Choose the correct velocity-time graph for each of the following questions. You may use a graph more than once or not at all.



J None is correct

52. Which velocity graph shows the object moving away from the origin at a steady (constant) velocity?

53. Which velocity graph shows the object standing still?

54. Which velocity graph shows the object moving toward the origin at a steady (constant) velocity?

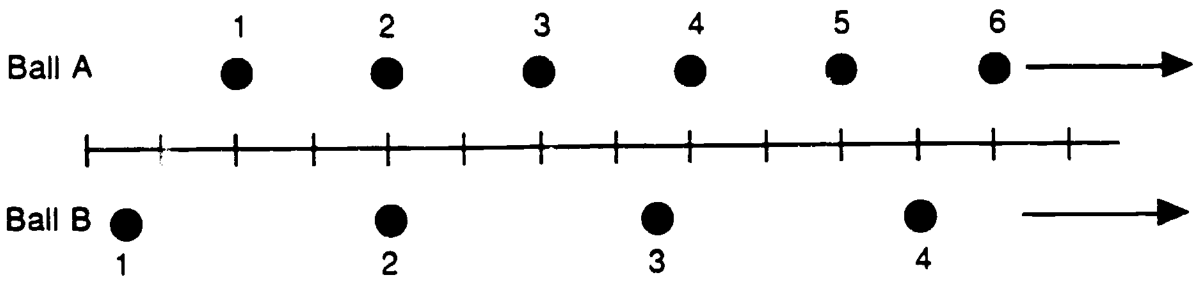
55. Which velocity graph shows the object moving away from the origin while slowing down?

56. Which velocity graph shows the object reversing direction?

57. Which velocity graph shows the object increasing its speed at a steady (constant) rate away from the origin?

58. Which velocity graph shows the object increasing its velocity and then slowing down?

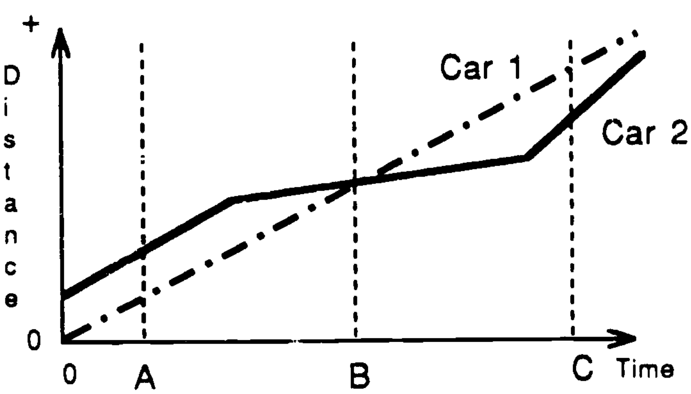
•Two balls A and B move at **constant** speeds on separate tracks. Positions occupied by the two balls at the **same time** are indicated in the figure below by **identical numbers.** The balls are moving to the right. Starting points are not shown.



59. Do the balls ever have the same speed?
    a. Yes, at instant 2.
    b. Yes, at instant 4.
    c. Yes, at all times.
    d. No.

60. The acceleration of the balls are related as follows;
    a. acceleration of A is greater than the acceleration of B.
    b. acceleration of A is equal to the acceleration of B and not equal to zero.
    c. acceleration of A is less than the acceleration of B.
    d. acceleration of A is equal to the acceleration of B and is equal to zero.

•The distance-time graph shows the motion of two different cars travelling at the same time in the same direction. Choose the time (A, B or C) when each of the statements is true. You may use a choice more than once or not at all. <u>If you think that none of the options is the correct, answer</u> J.

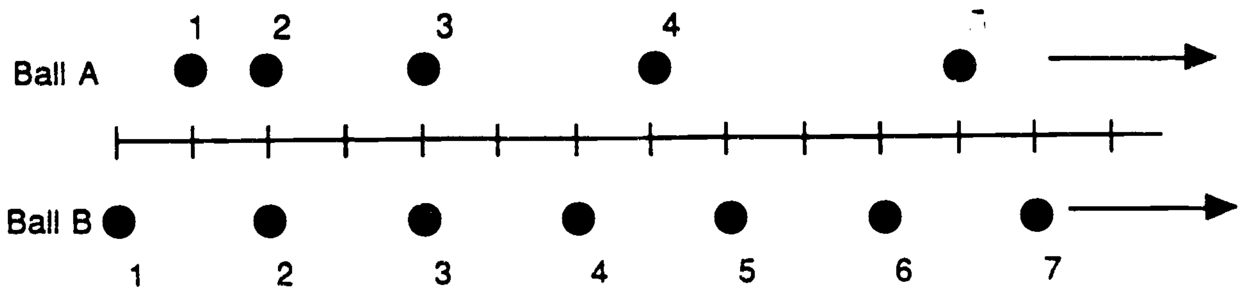


61. Car 2 is farther from the origin than car 1.

62. Car 2 is moving faster than car 1.

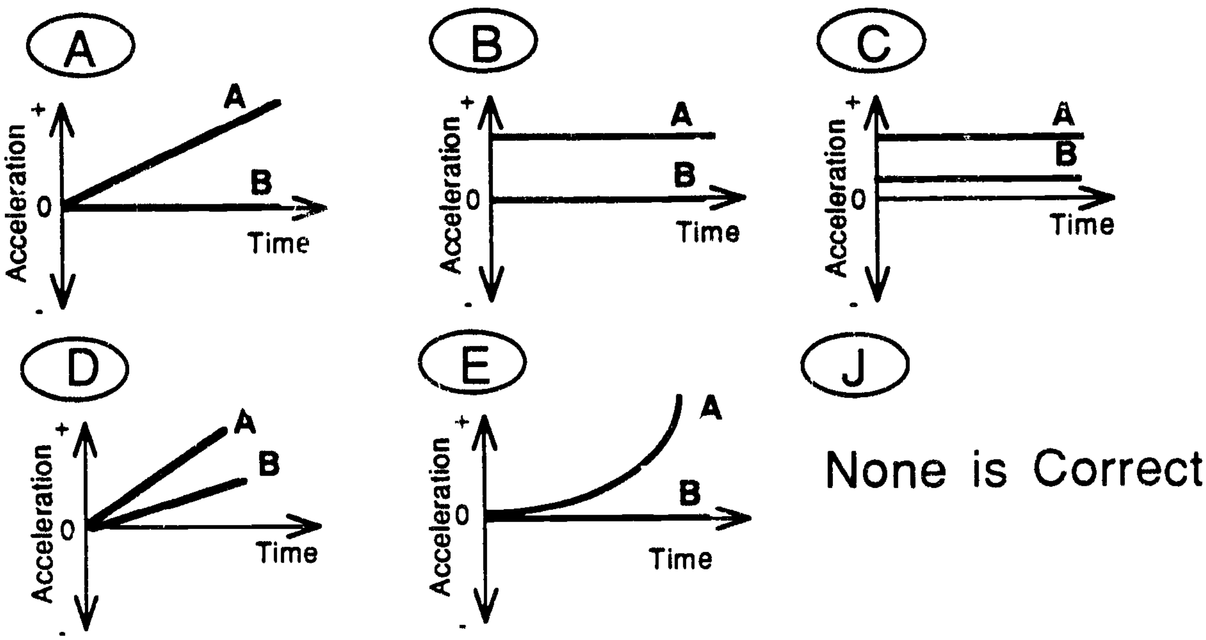
63. Both cars are moving at the same speed.

•Two balls, A and B move on separate tracks. Positions occupied by the two balls at the **same time** are indicated in the figure below by **identical numbers**. The balls are moving to the right. Starting points are not shown.



64. Do the balls ever have the same speed?
    a. No.
    b. Yes at instant 2.
    c. Yes at some interval between 3 and 4.
    d. Yes at some interval between 2 and 3.
    e. Yes at instant 4.

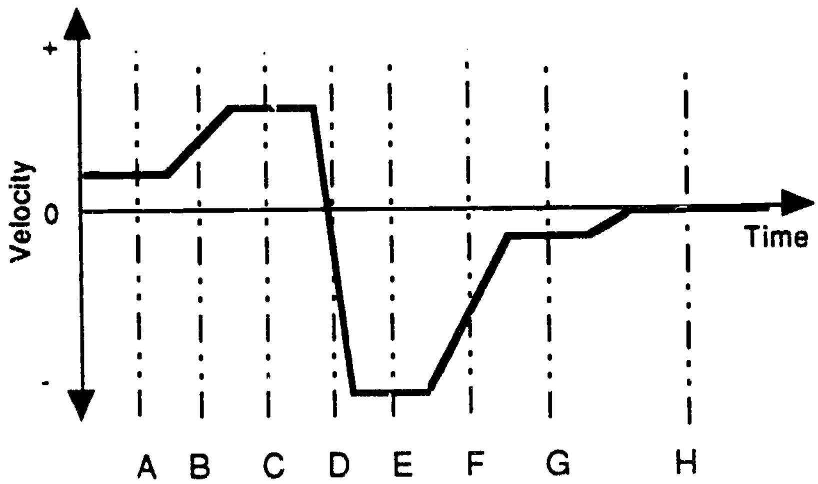
65. Which acceleration graph represents the motion of the two balls?



•An automobile starts at rest, speeds up at 10 meters/second^2.

66. What is the car's speed at the end of 5 seconds?
    a. 2 m/s
    b. 10 m/s
    c. 40 m/s
    d. 50 m/s
    j. none is correct

•The following velocity-time graph represents the motion of a car. Chose the time by selecting the conesponding letter. There is one correct answer for each question.

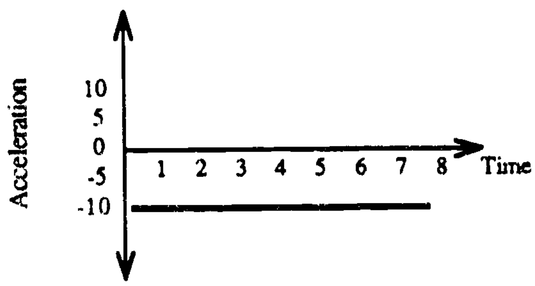


67. At which time is the car travelling fastest?

68. At which time is the car moving away from the origin at the slowest speed?

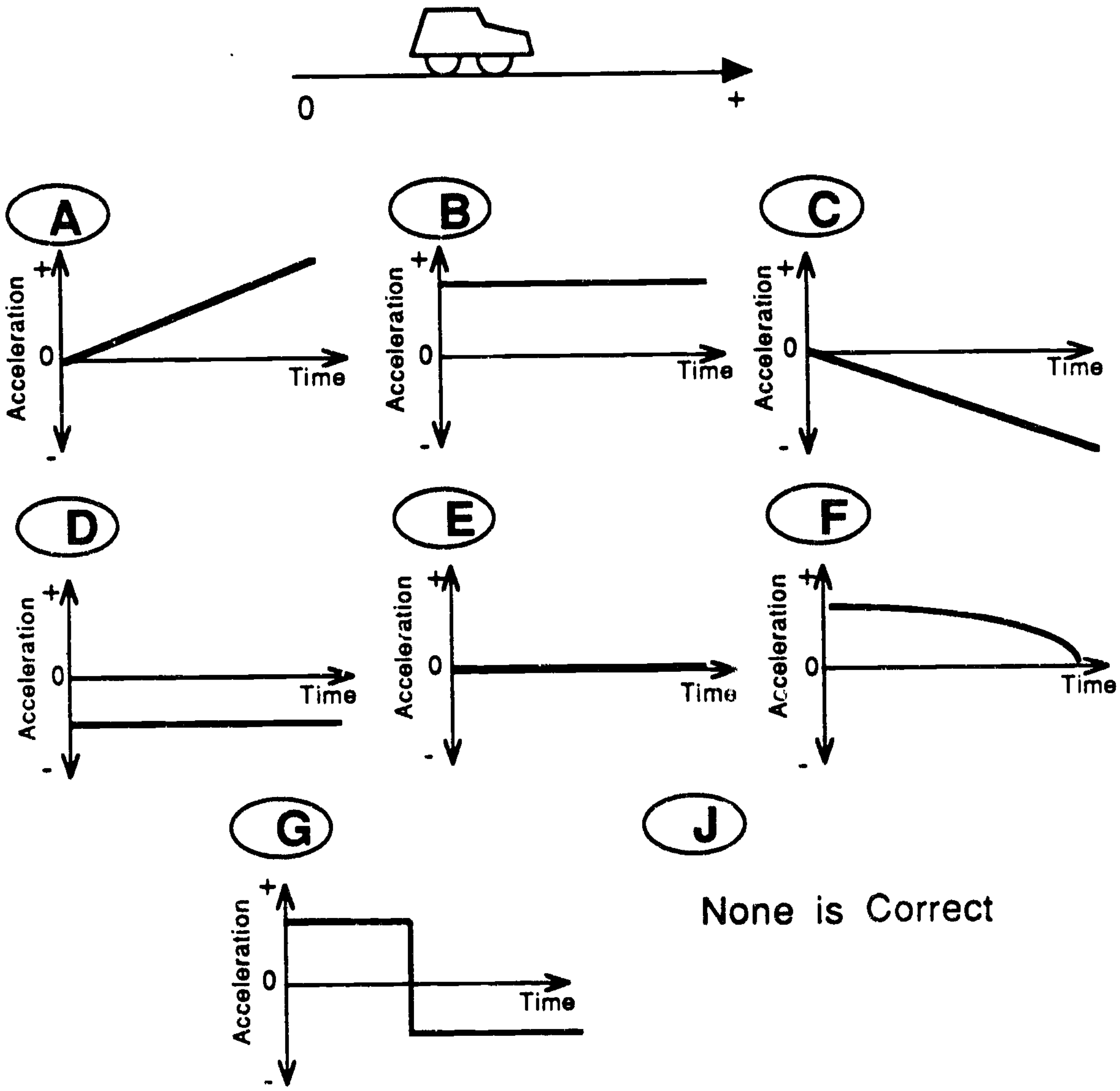
69. At which time is the car's velocity changing the most?

•An arrow is shot up into the air. It flies 100 meters high before it falls back to the earth. The arrow's flight is represented in the following acceleration-time graph. The arrow reaches the highest point in its flight at 3 seconds. The ground is considered the origin.



70. What is the acceleration on the arrow when it reaches its highest point?
   a. positive, constant and not equal to zero
   b. constant and equal to zero
   c. negative, constant and not equal to zero
   d. not constant and positive
   e. not constant and negative
   f. not constant and equal to zero at some point in time.

•A toy car can move in either direction along a horizontal line with the origin being on the left and the + distance axis to the right. Choose the letter of the acceleration-time graph which could correspond to the motion of the car described in each of the following. You may use a graph more than once or not at all. <u>If you think that none of the options is correct, answer J</u>.



71. The car moves away from the origin (to the right) at a constant velocity.

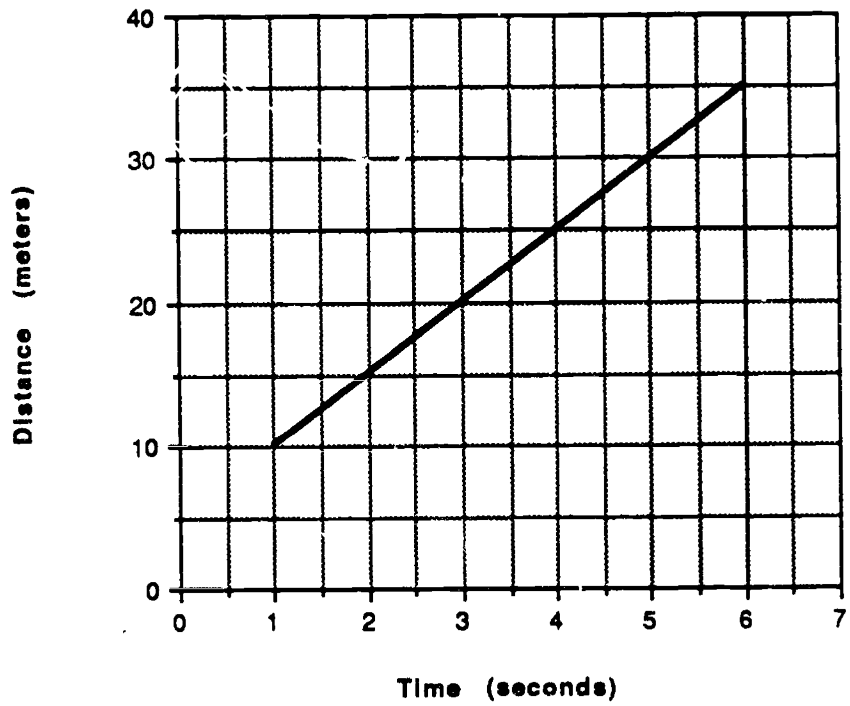
72. The car moves away from the origin (to the right) speeding up at a steady rate.

73. The car moves away from the origin (to the right) slowing down at a steady rate.

74. The car moves toward the origin (to the left) at a constant velocity.

75. The car moves toward the origin (to the left) speeding up at a steady rate.

•Given the following distance-time graph, determine the velocity of the object.



76. The velocity of the object is:
    a. 5 meters/second
    b. 2 meters/second
    c. 0 meters/second
    d. 0.2 meters/second
    e. 0.5 meters/second
    j. none is correct

77. The acceleration of the object is:
    a. increasing
    b. decreasing
    c. constant and **not** equal to zero
    d. constant and equal to zero
    j. none is correct

• A train travels 100 kilometers in 30 minutes.

78 . What is its speed?
    a. 300 kilometers/hour
    b. 3.33 kilometers/hour
    c. 30 kilometers/hour
    d. 50 kilometers/hours
    e. 200 kilometers/hour
    j. none is correct