DOCUMENT RESUME

ED 436 359		SE 061 806
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TITLE	A Comparison of the Quality of Integrated Freshman-Year Curriculum for Science, Engineering and Mathematics with a Conventional Curriculum.	
PUB DATE	1998-07-10	
NOTE	32p.	
PUB TYPE	Reports - Research (143)	
EDRS PRICE	MF01/PC02 Plus Postage.	
DESCRIPTORS	Engineering Education; Experimental Curriculum; Females; *Force; Higher Education; *Instructional Effectiveness; *Instructional Innovation; *Integrated Curriculum; Mathematics Education; Mechanics (Physics); Misconceptions; *Physics; Science Education; Technology Education	

ABSTRACT

This report describes a comparison of the effectiveness of two types of instruction on undergraduate students' learning of the concept of force. Findings indicate that students who participated in the Integrated Freshman Year Curriculum for Science, Engineering and Mathematics improved slightly more on the Force Concept Inventory than students who received traditional instruction, and that females in the integrated program improved significantly more than females in the conventional program. (WRM)

A Comparison of the Quality of Integrated Freshman-Year Curriculum for Science, Engineering and Mathematics with a Conventional Curriculum

by: Tosh Yamamoto

Force Concept Inventory to Compare the Quality of the Integrated Freshman-Year Curriculum for Science, Engineering & Mathematics with that of the Conventional Curriculum at Rose-Hulman Institute of Technology.

By Tosh Yamamoto

I. ABSTRACT

The purpose of this research was to look at the improvement of the understanding of the force concept in two groups of Rose-Hulman freshman students: one group is from the conventional curriculum where all engineering courses are taught as autonomous courses; the other from the integrated curriculum where mathematics, physics and chemistry are taught as one integrated course, which counts as three course-worth of credits.

In order to conduct this research, the Force Concept Inventory test developed by Hestenes at. al. (2) was employed. The gain of the pretest and the posttest for both groups was analyzed in the light of the groups, SAT scores before admission to college (both verbal and math), and gender. A two way analysis of covariance was the most appropriate for the analysis of the collected data.

This research found that the students in the Integrated Freshman-Year Curriculum for Science, Engineering and Mathematics improved slightly more than the students in the conventional curriculum. However, female students in the Integrated Freshman-Year Curriculum for Science, Engineering and Mathematics improved significantly more than the female students in the conventional curriculum.

II. BACKGROUND OF THE PROBLEM

A. INTRODUCTION

There is always room for improvement. This also applies to an educational institution. The engineering faculty at Rose-Hulman Institute of Technology had been developing an integrated freshman curriculum called the Integrated Freshman-Year Curriculum for Science, Engineering and Mathematics (henceforth, IFYCSEM). IFYCSEM was a new attempt to teach basic science and math to freshman students from a holistic view point. In IFYCSEM, freshman students took an integrated course containing math, physics and chemistry in one course which counted, credit-wise, as three conventional courses. Because of its nature, IFYCSEM was team-taught by four professors of different disciplines. Upon the admission to the school, all freshman students were informed of this pilot program and those who volunteered for it went through this innovative curriculum.

In order to compare the two groups of students who went through the two different curriculums, Rose-Hulman had to develop an assessment mechanism to (1) evaluate instruction in each curriculum and (2) to diagnose instruction in each curriculum. Of course, the goal of the research was to evaluate the effectiveness of IFYCSEM compared with the conventional curriculum and to prove that IFYCSEM was superior. As a preparation for conducting the research, a comparison group from the conventional curriculum was to be created. During the freshman orientation, the Force Concept Inventory test was given to all incoming students. When they finished the freshman year, the same test was given to them. The students in IFYCSEM were willing to take the posttest. However, the students from the conventional curriculum did not care about taking the posttest at the end of the freshman academic year. In order to obtain a high pretest/posttest retention rate, the school paid some amount of money to the students of the traditional curriculum who took the posttest.

This research used the data collected in the academic year of 1996. The total number of the students who took both pretest and posttest was 99, out of which 46 students were from IFYCSEM and the rest, from the conventional curriculum. The IFYCSEM group consisted of 38 male students and 8 female students. The conventional curriculum was composed of 40 male students and 13 female students.

IFYCSEM believed that the holistic approach to teaching science and Math would be better than the conventional approach to teaching subjects of different disciplines individually. IFYCSEM needed a good assessment tool to prove that engineering students in IFYCSEM improved more than the conventional curriculum. IFYCSEM employed the Force Concept Inventory test developed by Dr. David Hestenes, Dr. Malcolm Wells, and Dr. Gregg Swackhamer of Arizona State University, which will be seen in the next section.

B. RATIONALE

BRIEF HISTORY & THEORETICAL BASE

Because of the lack of predecessors in this field of assessment in IFYCSEM, Rose-Hulman used the Force Concept Inventory test developed by Hestenes et al. (1992). This section deals with its history and the rationale behind it.

Hestenes et al. (1992) developed the Force Concept Inventory to assess students overall understanding of the Newtonian concept of force. They observed that even engineering students began physics with a well-established system of common-personal experience and that these beliefs played a dominant role in introductory physics. Thus, they claim that engineering instruction that does not take these beliefs into consideration is not effective to most students.

Hestenes et al. (1992) found from the observation of most physics students that (1) common-sense beliefs about motion and force were incompatible with Newtonian concepts in most respects, (2) conventional physics instruction produced little change in these beliefs, (3) this result was independent of the instructor and the mode of instruction. An example of (1) would be: "The heavier a stone is, the faster it falls." They noticed that most students coped with the subject by rote memorization of isolated fragments to pass the course.

The traditional instruction lacked technical knowledge about how students thought and learned. Thus, Hestenes et al. (1992) claimed that teachers with technical knowledge and an instrument to help teachers probe and assess the common-sense beliefs of their students improved education. The central concept of Newtonian mechanics is force. Thus, Hestenes et al. (1992) developed the Force Concept Inventory to probe student beliefs on force and how their beliefs compared with the many dimensions of the Newtonian concept. (See Appendix VIII for a copy of the Force Concept Inventory test.) The Force Concept Inventory makes forced choices between Newtonian concepts and common-sense alternatives. Previously, it was not easy to find out that students believed common-sense alternatives, which were not compatible with Newtonian concepts. The force Concept Inventory consists of six conceptual dimensions: Kinematics, First Law, Second Law, Third Law, Superposition Principle, and Kinds of Force. Each dimension is probed by questions of more than one type. For each question, there is only one correct answer. It is important to point out that the Force Concept Inventory test is not intended to be a test of intelligence but a probe of belief systems. (See Appendix V and VI for Newtonian Concepts in the Inventory and a Taxonomy of Misconceptions Probed by the Inventory.)

The Force Concept Inventory test was given to more than 1500 high-school students and more than 500 university students. (See Appendix VII for the result.) Hestenes et al. (1992) concluded from the results from the table that math background was not a major factor in the high-school results and that a significant improvement was made by an effective teaching style. They also found out that there is no correlation of scores with socioeconomic level because computation of average scores for each level confirms their view. They resorted to a reason that the students who took physics were usually not typical of the socioeconomic levels. College level results were taken from the comparison of Arizona State University's Physics 105 taught by Professor Alan Van Heuvelen using new pedagogical techniques on the one hand with the regular Arizona State Physics 105 and the regular Harvard University Physics courses on the other. Although pretest scores did not show much different between the two groups, the posttest scores in Professor Heuvelen's group were clearly superior. From this clear evidence, Hestenes et al. (1992) concluded that pedagogy could make a difference in improving the force concept.

The time is an important variable in tests. For the Harvard students, the tests were administered on computers and they were able to spend as much time as they needed. However, they were not allowed to go back to correct answers once they moved on to the next question. The Harvard computers measured the average time of 23 minutes. The Arizona State classes were allowed 40 minutes for the Force Concept Inventory test.

Hestenes et al. (1992) further claimed the external validity of the Force Concept Inventory test because the data from seven different professors with more than a thousand students, which are shown in the table in Appendix VII, showed nearly identical posttest scores.

Hestenes et al. (1992) claimed that the Force Concept Inventory could be used for both instructional and research purposes with three areas of application. First, the Force

Concept Inventory test could be used as a diagnostic tool to identify and classify students misconceptions. This aspect was useful for teachers to know their students' misconceptions. Second, the Force Concept Inventory test was an accurate and reliable instrument for evaluating instruction. The larger the gain between the pretest and the posttest, the more effective the instruction was. Third, because the Force Concept Inventory could be used in colleges and universities to help determine if student understanding of introductory physics was sufficient for a more advanced course. They recommended to use it in conjunction with the Mechanic Baseline test developed by Hestenes and Wells (1992), which was supposed to measure students' problem solving ability.

REVIEW OF LITERATURE

Heller and Huffman (1995) claimed that the Force Concept Inventory test did not meet one of the common standards of test construction because from the students' point of view, the Force Concept Inventory did not test for a coherent, universal force concept, dimensions of a force concept, or any organized alternative beliefs such as impetus. They claimed that instead of looking at the total score, the analysis must also look at the correlation of test items that intended to measure the same dimension of the force concept from different situations in the physical world and, further, that the correctness rates of the answers from the two questions should be correlated. Thus, they concluded that although the Force Concept Inventory test was useful as a diagnostic tool and course evaluations, the interpretation of test scores must be made with caution and it should not be used to determine a placement of individual students.

Heller and Huffman (1995) agrees with Hestenes et al. (1992) that the face and content validity of the Force Concept Inventory test is reasonable. However, they pointed out inconsistencies in students' responses between test items that asked about the same dimension of the force concept after conducting a factor analysis to correlate the test items in the Force Concept Inventory. Although they admitted that the factor analysis was used during the early stages in the process of the test development, their finding affected the internal validity of the Force Concept Inventory test.

Hestenes and Halloun (1995) counter-argued that the concerns presented in Heller and Huffman (1995) were not justified because factor analysis was an inappropriate statistical tool to draw conclusions about either the validity of the Force Concept Inventory test or student concepts of force.

Due to the fact that this area of study was new and also due to the fact that the bibliographical materials were limited to the above mentioned three articles, this concludes the argument of this section. Heller and Huffman (1995)'s counter-argument not being very convincing, this research assumed that the position maintained by Hestenes et al. (1992) was correct.

ANTICIPATED OUTCOMES OF THIS RESEARCH

Because of the fact that the Force Concept Inventory test was the only available method to measure the improvement of the pedagogy, this research adopted this test as measuring the improvement of the students' force concept compared with that of the conventional students. It should be noted that IFYCSEM is an integration of physics, chemistry and math. The Force Concept Inventory test did not test students' math and chemistry concepts. Therefore, it only evaluated the outcomes from subsets of IFYCSEM and the conventional curriculum.

This research anticipated the following outcome:

> If IFYCSEM is superior to the conventional curriculum, the posttest score of the Force Concept Inventory test of IFYCSEM should show more gain than the posttest score of the conventional curriculum because the improvement of the score is claimed to be due to the better pedagogy.

This research intended to prove that a curriculum offering students a holistic view of various science subjects while showing students correlations between them was expected to surpass the conventional curriculum in their understanding of the physical world.

III. STATEMENT OF THE PROBLEM

GENERAL

The purpose of this research was to investigate the effectiveness of the IFYCSEM curriculum compared with the conventional curriculum in improving the students' understanding of the force concept. Freshman students began the curriculum with common-sense beliefs about motion and force which were not compatible with Newtonian concepts in most respects. Hestenes et al. (1992) claimed that in the conventional curriculum, instruction made little change in students' beliefs. Most students did not understand the most basic Newtonian concepts. They simply passed courses by rote memorization of isolated fragments of concepts or by carrying out meaningless tasks.

SPECIFIC

This research purported to prove that the IFYCSEM curriculum offered students more understanding of the force concept compared with the conventional curriculum. Since the conversion to an coeducational institution in 1994, the institution noticed a difference in understanding science between male students and female students. The conventional pedagogy was based solely on male students in the classroom. If the conventional pedagogy was proven to fail in educating female students, this research would offer a new start in the development of engineering curriculum for freshman students.

HYPOTHESES

This research investigated the following hypotheses:

Hypothesis I

There is no difference between the means of the gain between the pretest and the post test for the IFYCSEM students and the means of the gain between the pretest and the post test for the conventional curriculum.

Hypothesis II

Between the two curricula, there is no difference between the means of the gain between the pretest and the post test for male students and the means of the gain between the pretest and the post test for female students.

If Hypothesis I was proved to be true, the IFYCSEM curriculum did not show any improvement over the conventional curriculum. If Hypothesis II was proved to be true, both male and female students in the two curricula understood the force concepts in the same manner.

If both hypotheses were proved to be true, it was concluded that both male and female students understood the force concepts equally and that the two curricula had the same effect on both male and female students. Thus, the IFYCSEM curriculum failed to demonstrate superiority over the conventional curriculum.

IV. METHODOLOGY

Source, Groups, and Materials

This research used the data collected in the academic year of 1996. The data was provided by the Institute Assessment Committee directed by Dr. Gloria Rogers. The available data were (a) which group a student belonged to, (b) the gender of the students, (c) SAT scores (both verbal and math), (d) pretest and posttest scores. The total number of the students who took both pretest and posttest was 99, out of which 46 students were from IFYCSEM and the rest, from the conventional curriculum. The IFYCSEM group consisted of 38 male students and 8 female students. The conventional curriculum were composed of 40 male students and 13 female students. Because there was the total of 116 freshman students admitted to the school that year, it turned out that over 85 % of the freshman students participated in the project, which clearly represented the majority of the population.

In order to compare the two groups of students who went through the two different curriculums, Rose-Hulman had to develop an assessment mechanism to (1) evaluate instruction in each curriculum and (2) to diagnose instruction in each curriculum. Of course, the goal of the research was to evaluate the effectiveness of IFYCSEM compared with the conventional curriculum and to prove that IFYCSEM was superior. As a preparation for conducting a research, a comparison group from the conventional curriculum was to be created. During the freshman orientation, the Force Concept Inventory test was given to all students. When they finished the freshman year, the same test was given to them. The students in IFYCSEM were willing to take the posttest. However, the students from the conventional curriculum did not care about taking the posttest. In order to obtain a high pretest to posttest retention rate, the school paid some amount of money to those students who took the posttest from the traditional curriculum.

TESTS and DESIGN

The Force Concept Inventory test developed by Hestenes et al. (1992) was used without any modification. The same test was used at the beginning of the freshman year and at the end of the freshman year. For each test, students were given 50 minutes to complete. Judging from the fact that Harvard University students spent the average of 28 minutes and that Arizona State University students spent 40 minutes to complete during the final examination, the amount of the time of 50 minutes was considered to be appropriate at Rose-Hulman. When students finished, they were allowed to turn in the test and leave the test room. Both groups of students took the test in the same room.

The results were categorized according to: (a) groups, (b) the gender of the students, (c) SAT scores (both verbal and math), (d) pretest and posttest scores.

ANALYSIS

In order to test the hypotheses, a two-way analysis of covariance was conducted. Furthermore, the means of the gain between the pretest and the posttest of the male students, the female students, and the entire group for the two curricula were analyzed.

RESULTS

The results of this research can be found in Table I and Table II and also are represented graphically in the appendix in Figure III-b.

Table I shows the comparison of the means of subgroups. All subgroups in the two curricula showed improvement in understanding of the force concept. It is merely not significant. But there is a significant difference in the means of female subgroups in the two curricula. Especially the female subgroup in the IFYCSEM showed improvement more than the female subgroup in the conventional curriculum.

Table I

Results of Force Concept Inventory Test

Comparison of the Means between subgroups

	IC Pretest	IC Posttest	IC Gain	w/o IC Pretest	w/o IC Posttest	w/o IC Gain
Mean (M & F)	15	19	4	14.94	17.64	2.70
Mean (F)	11	15	4	12.15	13.08	0.92
Mean (M)	16	20	4	15.85	19.13	3.28

Table II shows the result of the two-way analysis of covariance. Although the difference in curriculum did not show much significance, the gender difference seems to be significant.

Table II

Analysis of Variance by Gain, Gender, and IFYCSEM

Source of Variation	DF	F	Sig of F
Main Effects	2	3.381	.038
Gender	1	2.498	.117
IFYCSEM	1	3.234	.075
2-Way Interactions	1	1.827	.180
Gender IFYCSEM	1	1.827	.180

99 cases were processed.

0 cases were missing.

VI. DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Results of the research provided evidence that although there was not a significant difference between the IFYCSEM curriculum and the conventional curriculum, there was significant difference between the female subgroups between the IFYCSEM curriculum and the conventional curriculum. The results might infer that the holistic instructional approach had a positive impact toward female students but not much impact on male students. From the pedagogical point of view, female students in the IFYCSEM curriculum showed more improvement in understanding the force concept. However, it should be noted that there were only 9 female students in the IFYCSEM curriculum group. Before jumping to a conclusion, the research must be expanded to include more female students for testing.

In passing, it should be pointed out that SAT math scores had nothing to do with the understanding of the force concepts, which conformed to the conclusion drawn by Hestenes et al. (1992). In general, it is safe to say that both SAT verbal and math scores did not play any role in affecting the results of this research.

Although the IFYCSEM curriculum was intended to teach physics, chemistry and math in an integrated way, the research only made use of the Force Concept Inventory test to evaluate students' physics understanding. It was not fair to conclude that the IFYCSEM curriculum was not better than the conventional one by only looking at a part of the IFYCSEM curriculum. It is recommended that a full fledged testing device to assess students' chemistry and math understandings as well as physics understanding be developed to conduct a research to test the full validity of the IFYCSEM curriculum. Therefore, a much further study of this area needs to be done before coming to a conclusion. Rose-Hulman should look into development of a full-fledged test to grasp the holistic understanding of science and math to evaluate the IFYCSEM curriculum holistically.

VII. REFERENCES

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I. The Data for the IFYCSEM Curriculum

IFYCSEM	Gender	SAT_Verb	SAT_Math	PreTest	PostTest	Gain(Post-Pre)
2	F	530	580	7	12	5
2	F	530	650	12	17	5
2	F	660	610	13	8	-5
2	F	480	590	7	9	2
2	F	530	680	13	22	9
2	F	720	800	12	19	7
2	F	580	740	8	11	3
2	F	670	750	14	18	4
2	M	470	630	18	16	-2
2	M	800	720	21	26	5
2	M	610	680	17	21	4
2	M	560	710	18	24	6
2	M	470	570	13	20	7
2	M	470	660	17	22	5
2	M	720	800	17	23	6
2	M	660	720	22	27	5
2	M	520	590	16	22	6
2	M	550	720	18	23	5
2	M	370	610	12	18	6
2	M	700	690	19	25	6
2	M	520	670	11	12	1
2	M	610	680	6	4	-2
2	M	670	630	13	24	11
2	M	680	760	12	23	11
2	M	560	690	22	22	0
2	M	660	720	17	27	10
2	M	800	740	23	25	2
2	M	500	640	24	26	2
2	M	580	730	25	24	-1
2	M	530	630	16	17	1
2	M	560	660	14	11	-3
2	M	470	710	12	8	-4
2	M	470	660	12	14	2
2	M	550	720	16	25	9
2	M	560	630	15	18	3
2	M	550	590	11	18	7
2	M	590	680	11	21	10
2	M	560	660	15	23	8
2	M	570	710	22	24	2
2	M	580	740	10	18	8
2	M	530	690	24	24	0
2	M	530	750	15	14	-1
2	M	580	710	12	16	4
2	M	700	740	22	24	2
2	M	590	670	15	20	5
2	M	740	650	17	22	5

The IFYCSEM Curriculum: Comparison of Means

	Verbal	Math	Pretest	Posttest	Gain
Mean (M & F)	583.48	681.74	15.35	19.28	3.93
Mean (F)	587.50	675.00	10.75	14.50	3.75
Mean (M)	582.63	683.16	16.32	20.29	3.97

II. The Data for the Conventional Curriculum

IFYCSEM	Gender	SAT_Verb	SAT_Math	PreTest	PostTest	Gain(Post-Pre)
1	F	460	640	3	6	3
1	F	550	680	12	15	3
1	F	580	710	18	17	-1
1	F	680	720	16	18	2
1	F	680	630	10	13	3
1	F	680	680	19	14	-5
1	F	710	630	17	17	0
1	F	580	740	13	15	2
1	F	610	630	7	1	-6
1	F	590	620	9	16	7
1	F	510	710	10	11	1
1	F	580	650	12	11	-1
1	F	690	580	12	16	4
1	M	660	740	14	19	5
1	M	550	700	18	20	2
1	M	580	680	18	25	7
1	M	540	710	14	13	-1
1	M	610	770	23	24	1
1	M	490	610	16	22	6
1	M	530	630	14	18	4
1	M	570	630	17	16	-1
1	M	490	750	10	13	3
1	M	530	700	17	18	1
1	M	710	710	10	14	4
1	M	510	650	14	20	6
1	M	600	690	26	27	1
1	M	610	790	9	15	6
1	M	510	650	15	16	1
1	M	570	770	15	7	-8
1	M	660	700	16	20	4
1	M	740	740	21	24	3
1	M	600	650	15	19	4
1	M	490	680	15	25	10
1	M	550	660	14	10	-4
1	M	620	710	18	19	1
1	M	490	710	11	10	-1
1	M	660	740	19	25	6
1	M	530	650	15	18	3
1	M	690	770	23	26	3
1	M	510	720	13	23	10
1	M	430	680	11	12	1
1	M	720	760	22	20	-2
1	M	530	690	18	24	6
1	M	680	750	14	21	7
1	M	500	600	7	9	2
1	M	550	720	17	22	5
1	M	610	770	17	26	9
1	M	470	570	15	18	3
1	M	460	650	11	19	8
1	M	500	580	19	26	7
1	M	450	600	17	21	4
1	M	530	710	22	20	-2
1	M	410	610	14	21	7

The Conventional Curriculum: Comparison of Means

	Verbal	Math	Pretest	Posttest	Gain
Mean (M & F	572.45	683.40	14.94	17.64	2.70
Mean (F)	607.69	663.08	12.15	13.08	0.92
Mean (M)	561.00	690.00	15.85	19.13	3.28

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Comparison of the Means between the Conventional Curriculum and the Traditional Curriculum

	IC Pretest	IC Posttest	IC Gain	w/o IC Pretest	w/o IC Posttest	w/o IC Gain
Mean (M & F	15	19	4	14.94	17.64	2.70
Mean (F)	11	15	4	12.15	13.08	0.92
Mean (M)	16	20	4	15.85	19.13	3.28

Note: "IC" means the IFYCSEM curriculum and "w/o IC" means the conventional curriculum.

III. Comparison of Mean Scores between the Two Curricula

a. Numeric Representation in a Table. (For ease of exposition, the table is repeated from Table II.)

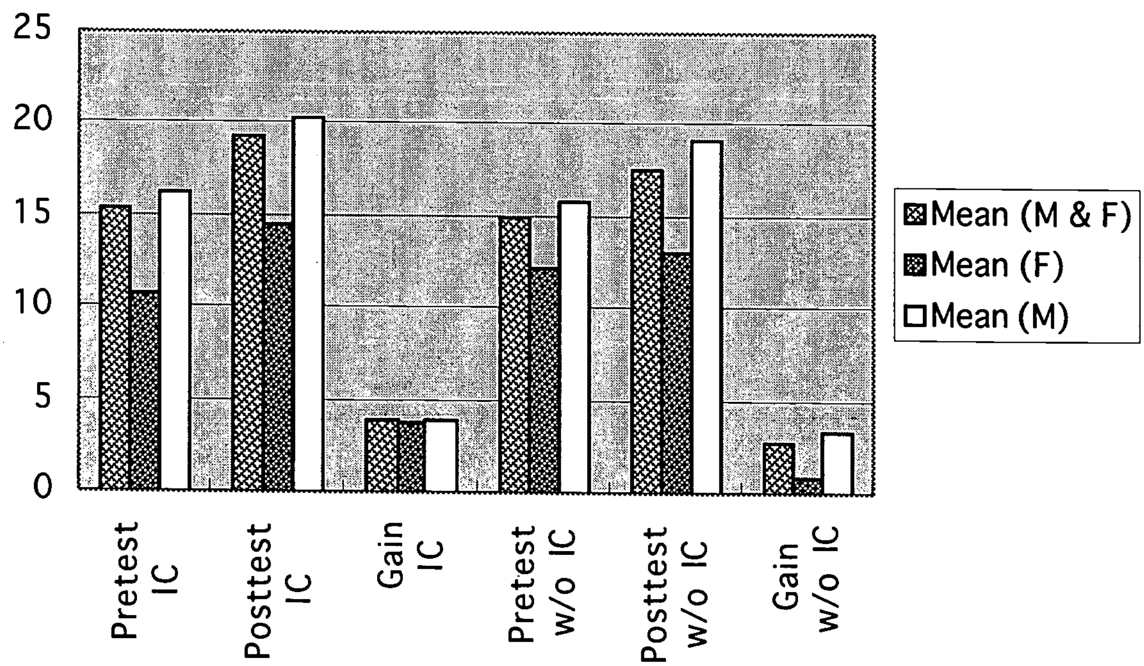
Analysis of Variance by Gain, Gender, and IFYCSEM

Source of Variation	DF	F	Sig of F
Main Effects	2	3.381	.038
Gender	1	2.498	.117
IFYCSEM	1	3.234	.075
2-Way Interactions	1	1.827	.180
Gender IFYCSEM	1	1.827	.180

99 cases were processed.
0 cases were missing.

b. Graphic Representation of III-a.

Results: Force Concept Inventory Test



IV. Correlations

Correlation:

- - Correlation Coefficients - -

	GAIN	GENDER	IFYCSEM	SAT_MATH	SAT_VERB
GAIN	1.0000 (99) P= .	.1899 (99) P= .060	.1339 (99) P= .186	.0316 (99) P= .757	.0635 (99) P= .532
GENDER	.1899 (99) P= .060	1.0000 (99) P= .	.0652 (99) P= .521	.0955 (99) P= .347	-.1039 (99) P= .306
IFYCSEM	.1339 (99) P= .186	.0652 (99) P= .521	1.0000 (99) P= .	-.0148 (99) P= .885	.0634 (99) P= .533
SAT_MATH	.0316 (99) P= .757	.0955 (99) P= .347	-.0148 (99) P= .885	1.0000 (99) P= .	.4608 (99) P= .000
SAT_VERB	.0635 (99) P= .532	-.1039 (99) P= .306	.0634 (99) P= .533	.4608 (99) P= .000	1.0000 (99) P= .

(Coefficient / (Cases) / 2-tailed Significance)

" . " is printed if a coefficient cannot be computed

V. Newtonian Concepts in the Inventory

Table I. Newtonian Concepts in the Inventory.

	Inventory Item
0. Kinematics	
Velocity discriminated from position	20E
Acceleration discriminated from velocity	21D
Constant acceleration entails	
parabolic orbit	23D, 24E
changing speed	25B
Vector addition of velocities	(7E)
1. First Law	
with no force	4B, (6B), 10B
velocity direction constant	26B
speed constant	8A, 27A
with cancelling forces	18B, 28C
2. Second Law	
Impulsive force	(6B), (7E)
Constant force implies	
constant acceleration	24E, 25B
3. Third Law	
for impulsive forces	2E, 11E
for continuous forces	13A, 14A
4. Superposition Principle	
Vector sum	19B
Cancelling forces	(9D), 18B, 28C
5. Kinds of Force	
5S. Solid contact	
passive	(9D), (12 B,D)
Impulsive	15C
Friction opposes motion	29C
5F. Fluid contact	
Air resistance	22D
buoyant (air pressure)	12D
5G. Gravitation	5D, 9D, (12B,D), 17C, 18B, 22D
acceleration independent of weight	1C, 3A
parabolic trajectory	16B, 23D

Note. This Table is from: Hestenes, David. Wells, Malcolm. & Swackhamer, Gregg. (1992). Force Concept Inventory. The Physics Teacher, 30, 141-58

VI. A Taxonomy of Misconceptions Probed by the Inventory.

Table A Taxonomy of Misconceptions Probed by the Inventory. Presence of the misconceptions is suggested by selection of the corresponding Inventory Item.

	Inventory Item
0. Kinematics	
K1. position-velocity undiscriminated	20B,C,D
K2. velocity-acceleration undiscriminated	20A; 21B,C
K3. nonvectorial velocity composition	7C
1. Impetus	
I1. impetus supplied by "hit"	9B,C; 22B,C,E; 29D
I2. loss/recovery of original impetus	4D; 6C,E; 24A; 26A,D,E
I3. impetus dissipation	5A,B,C; 8C; 16C,D; 23E; 27C,E; 29B
I4. gradual/delayed impetus build-up	6D; 8B,D; 24D; 29E
I5. circular impetus	4A,D; 10A
2. Active Force	
AF1. only active agents exert forces	11B; 12B; 13D; 14D; 15A,B; 18D; 22A
AF2. motion implies active force	29A
AF3. no motion implies no force	12E
AF4. velocity proportional to applied force	25A; 28A
AF5. acceleration implies increasing force	17B
AF6. force causes acceleration to terminal velocity	17A; 25D
AF7. active force wears out	25C,E
3. Action/Reaction Pairs	
AR1. greater mass implies greater force	2A,D; 11D; 13B; 14B
AR2. most active agent produces greatest force	13C; 11D; 14C
4. Concatenation of Influences	
CI1. largest force determines motion	18A,E; 19A
CI2. force compromise determines motion	4C, 10D; 16A; 19C,D; 23C; 24C
CI3. last force to act determines motion	6A; 7B; 24B; 26C
5. Other Influences on Motion	
CF. Centrifugal force	4C,D,E; 10C,D,E
Ob. Obstacles exert no force	2C; 9A,B; 12A; 13E; 14E
Resistance	
R1. mass makes things stop	29A,B; 23A,B?
R2. motion when force overcomes resistance	28B,D
R3. resistance opposes force/impetus	28E
Gravity	
G1. air pressure-assisted gravity	9A; 12C; 17E; 18E
G2. gravity intrinsic to mass	5E; 9E; 17D
G3. heavier objects fall faster	1A; 3B,D
G4. gravity increases as objects fall	5B; 17B
G5. gravity acts after impetus wears down	5B; 16D; 23E

Note. This Table is from: Hestenes, David. Wells, Malcolm. & Swackhamer, Gregg. (1992). Force Concept Inventory. The Physics Teacher, 30, 141-58

VII. Inventory and Baseline Scores

Table III. Inventory and Baseline Scores.

Class	Inventory Pretest % (S. Dev.)	Inventory Posttest % (S. Dev.)	Baseline Posttest % (S. Dev.)	Posttest Number of Students N
High School				
Arizona Reg.	27 (11)	48(16)	32 (11)	612
Wells Reg.	28 (14)	64 (20)	42 (16)	18
Chicago Reg.	27	42		56
Arizona Hon.	33 (13)	56 (19)	37 (15)	118
Wells Hon.	42 (18)	78 (15)	62 (17)	30
Swackhamer Hon.	28	66	47	63
Arizona AP	41 (16)	57 (18)	39 (15)	33
Swackhamer AP	73	85		11
University				
Van Heuvelen 105	34 (14)	63 (18)	61 (18)	116
Wells 105	36	68	43	44
Arizona State Reg.	52 (19)	63 (18)	48 (15)	139
Harvard Reg.		77 (15)	66 (14)	186
Harvard Honors			73 (11)	75

Remarks: Mean scores (%) and standard deviations on all tests are given in percent. N is the number of students taking the posttest; variations in the numbers taking pre- and posttests were judged to be insignificant or, at least, uninformative. Arizona Reg. combines data from 15 teachers. Chicago Reg. are regular high-school classes in the Chicago area. The Chicago Reg. teacher employed neither the Wells nor the A. Van Heuvelen teaching methods.

Note. This Table is from: Hestenes, David. Wells, Malcolm. & Swackhamer, Gregg. (1992). Force Concept Inventory. The Physics Teacher, 30, 141-58

VI.A Force Concept Inventory Test

Force Conecpt Inventory Test

1. Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two story building at the same instant of time. The time it takes the balls to reach the ground below will be:

   (A) about half as long for the heavier ball.
   (B) about half as long for the lighter ball.
   (C) about the same time for both balls.
   (D) considerably less for the heavier ball, but not necessarily half as long.
   (E) considerably less for the lighter ball, but not necessarily half as long.

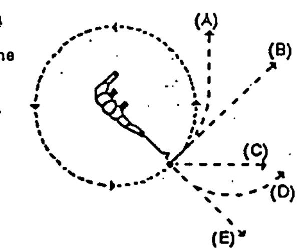
2. Imagine a head-on collision between a large truck and a small compact car. During the collision,

   (A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
   (B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
   (C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
   (D) the truck exerts a force on the car but the car doesn't exert a force on the truck.
   (E) the truck exerts the same amount of force on the car as the car exerts on the truck.

3. Two steel balls, one of which weighs twice as much as the other, roll off of a horizontal table with the same speeds. In this situation:

   (A) both balls impact the floor at approximately the same horizontal distance from the base of the table.
   (B) the heavier ball impacts the floor at about half the horizontal distance from the base of the table than does the lighter.
   (C) the lighter ball impacts the floor at about half the horizontal distance from the base of the table than does the heavier.
   (D) the heavier ball hits considerably closer to the base of the table than the lighter, but not necessarily half the horizontal distance.
   (E) the lighter ball hits considerably closer to the base of the table than the heavier, but not necessarily half the horizontal distance.

4. A heavy ball is attached to a string and swung in a circular path in a horizontal plane as illustrated in the diagram to the right. At the point indicated in the diagram, the string suddenly breaks at the ball. If these events were observed from directly above, indicate the path of the ball after the string breaks.

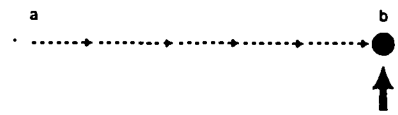


1

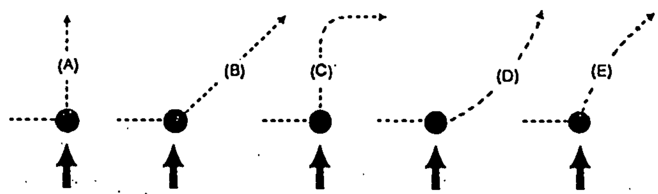
5. A boy throws a steel ball straight up. Disregarding any effects of air resistance, the force(s) acting on the ball until it returns to the ground is (are):

   (A) its weight vertically downward along with a steadily decreasing upward force.
   (B) a steadily decreasing upward force from the moment it leaves the hand until it reaches its highest point beyond which there is a steadily increasing downward force of gravity as the object gets closer to the earth.
   (C) a constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point, after which there is only the constant downward force of gravity.
   (D) a constant downward force of gravity only.
   (E) none of the above, the ball falls back down to the earth simply because that is its natural action.

- Use the statement and diagram below to answer the next four questions:
- The diagram depicts a hockey puck sliding, with a constant velocity, from point "a" to point "b" along a frictionless horizontal surface. When the puck reaches point "b", it receives an instantaneous horizontal "kick" in the direction of the heavy print arrow.



6. Along which of the paths below will the hockey puck move after receiving the "kick"?



7. The speed of the puck just after it receives the "kick"?

   (A) Equal to the speed "v_o" it had before it received the "kick".
   (B) Equal to the speed "v" it acquires from the "kick", and independent of the speed "v_o".
   (C) Equal to the arithmetic sum of speeds "v_o" and "v".
   (D) Smaller than either of speeds "v_o" or "v".
   (E) Greater than either of speeds "v_o" or "v", but smaller than the arithmetic sum of these two speeds.

2

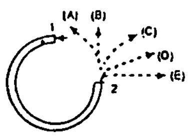
8. Along the frictionless path you have chosen, how does the speed of the puck vary after receiving the "kick"?

   (A) No change.
   (B) Continuously increasing.
   (C) Continuously decreasing.
   (D) Increasing for a while, and decreasing thereafter.
   (E) Constant for a while, and decreasing thereafter.

9. The main forces acting, after the "kick", on the puck along the path you have chosen are:

   (A) the downward force due to gravity and the effect of air pressure.
   (B) the downward force of gravity and the horizontal force of momentum in the direction of motion.
   (C) the downward force of gravity, the upward force exerted by the table, and a horizontal force acting on the puck in the direction of motion.
   (D) the downward force of gravity and an upward force exerted on the puck by the table.
   (E) gravity does not exert a force on the puck, it falls because of the intrinsic tendency of the object to fall to its natural place.

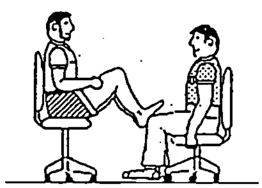
10. The accompanying diagram depicts a semicircular channel that has been securely attached, in a horizontal plane, to a table top. A ball enters the channel at "1" and exits at "2". Which of the path representations would most nearly correspond to the path of the ball as it exits the channel at "2" and rolls across the table top.



• Two students, student "a" who has a mass of 95 kg and student "b" who has a mass of 77 kg sit in identical office chairs facing each other. Student "a" places his bare feet on student "b's" knees, as shown below. Student "a" then suddenly pushes outward with has feet, causing both chairs to move.

11. In this situation,

   (A) neither student exerts a force on the other.
   (B) student "a" exerts a force on "b", but "b" doesn't exert any force on "a".
   (C) each student exerts a force on the other but "b" exerts the larger force.
   (D) each student exerts a force on the other but "a" exerts the larger force.
   (E) each student exerts the same amount of force on the other.



"a" "b"

3

12. A book is at rest on a table top. Which of the following force(s) is(are) acting on the book?

   1. A downward force due to gravity.
   2. The upward force by the table.
   3. A net downward force due to air pressure.
   4. A net upward force due to air pressure.

   (A) 1 only
   (B) 1 and 2
   (C) 1, 2, and 3
   (D) 1, 2, and 4
   (E) none of these, since the book is at rest there are no forces acting on it.

• Refer to the following statement and diagram while answering the next two questions.

A large truck breaks down out on the road and receives a push back into town by a small compact car.

13. While the car, still pushing the truck, is speeding up to get up to cruising speed;

   (A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
   (B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
   (C) the amount of force of the car pushing against the truck is greater than that of the truck pushing against the car.
   (D) the car's engine is running so it applies a force as it pushes against the truck but the trucks engine is not running so it can't push back against the car, the truck is pushed forward simply because it is in the way of the car.
   (E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

14. After the person in the car, while pushing the truck, reaches the cruising speed at which he/she wishes to continue to travel at a constant speed;

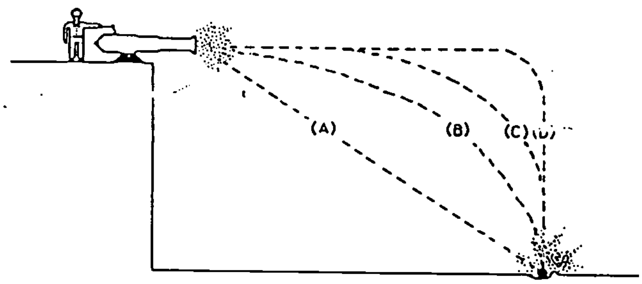
   (A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
   (B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
   (C) the amount of force of the car pushing against the truck is greater than that of the truck pushing against the car.
   (D) the car's engine is running so it applies a force as it pushes against the truck but the trucks engine is not running so it can't push back against the car, the truck is pushed forward simply because it is in the way of the car.
   (E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

4

15. When a rubber ball dropped from rest bounces off the floor, its direction of motion is reversed because;

(A) energy of the ball is conserved.
(B) momentum of the ball is conserved.
(C) the floor exerts a force on the ball that stops its fall and then drives it upward.
(D) the floor is in the way and the ball has to keep moving.
(E) none of the above.

16. Which of the paths in the diagram to the right best represents the path of the cannon ball?



17. A stone falling from the roof of a single story building to the surface of the earth;

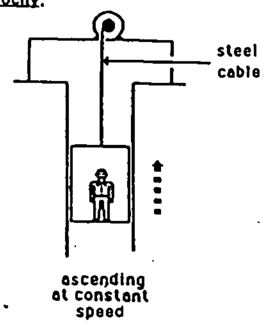
(A) reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
(B) speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational attraction.
(C) speeds up because of the constant gravitational force acting on it.
(D) falls because of the intrinsic tendency of all objects to fall toward the earth.
(E) falls because of a combination of the force of gravity and the air pressure pushing it downward.

5

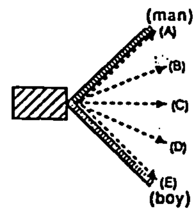
- When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.

18. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving up the shaft at a constant velocity;

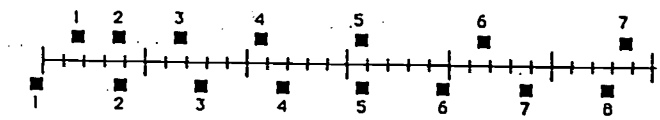
(A) the upward force on the elevator by the cable is greater than the downward force of gravity.
(B) the amount of upward force on the elevator by the cables equal to that of the downward force of gravity
(C) the upward force on the elevator by the cable is less than the down ward force of gravity.
(D) it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
(E) the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.



19. Two people, a large man and a boy, are pulling as hard as they can on two ropes attached to a crate as illustrated in the diagram to the right. Which of the indicated paths (A-E) would most likely correspond to the path of the crate as they pull it along?



- The positions of two blocks at successive 0.20 second time intervals are represented by the numbered squares in the diagram below. The blocks are moving toward the right.



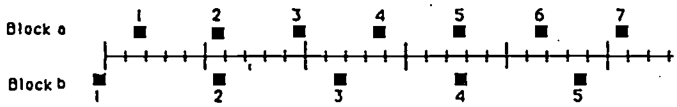
(continued on the next page)

6

20. Do the blocks ever have the same speed?

(A) No.
(B) Yes, at instant 2.
(C) Yes, at instant 5.
(D) Yes, at instant 2 and 5.
(E) Yes, at some time during interval 3 to 4.

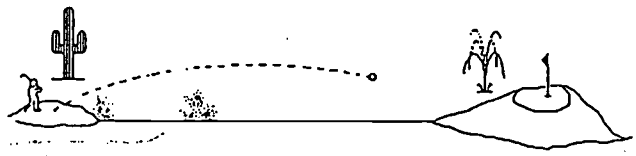
- The positions of two blocks at successive equal time intervals are represented by numbered squares in the diagram below. The blocks are moving toward the right.



21. The acceleration of the blocks are related as follows:

(A) acceleration of "a" > acceleration of "b"
(B) acceleration of "a" = acceleration "b" > 0
(C) acceleration of "b" > acceleration "a"
(D) acceleration of "a" = acceleration of "b" = 0
(E) not enough information to answer.

22. A golf ball driven down a fairway is observed to travel through the air with a trajectory (flight path) similar to that in the depiction below.



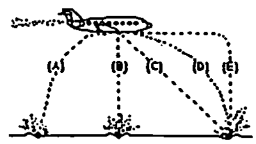
Which following force(s) is(are) acting on the golf ball during its entire flight?

1. the force of gravity
2. the force of the "hit"
3. the force of air resistance

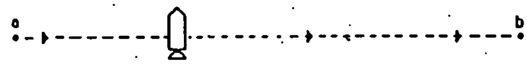
(A) 1 only
(B) 1 and 2
(C) 1, 2, and 3
(D) 1 and 3
(E) 2 and 3

7

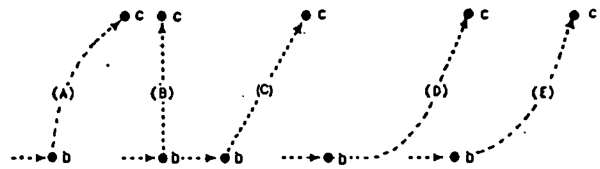
23. A bowling ball accidently falls out of the cargo bay of an airliner as it flies along in a horizontal direction. As seen from the ground, which path would the bowling ball most closely follow after leaving the airplane?



- When answering the next four questions, refer to the following statement and diagram.
- A rocket, drifting sideways in outer space from position "a" to position "b", is subject to no outside forces. At "b", the rocket's engine starts to produce a constant thrust at right angles to line "ab". The engine turns off again as the rocket reaches some point "c".



24. Which path below best represents the path of the rocket between "b" and "c"?



25. As the rocket moves from "b" to "c", its <u>speed</u> is

(A) constant.
(B) continuously increasing.
(C) continuously decreasing.
(D) increasing for a while and constant thereafter.
(E) constant for a while and decreasing thereafter.

8

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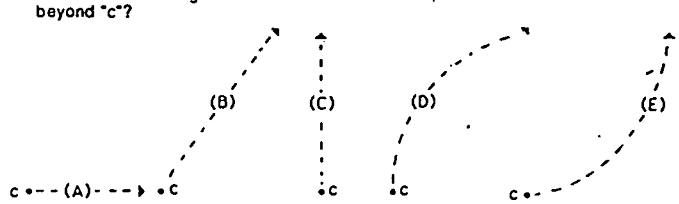
27

26. At "c" the rocket's engine is turned off. Which of the paths below will the rocket follow beyond "c"?



27. Beyond "c", the speed of the rocket is:

(A) constant.
(B) continuously increasing.
(C) continuously decreasing.
(D) increasing for a while and constant thereafter.
(E) constant for a while and decreasing thereafter.

28. A large box is being pushed across the floor at a constant speed of 4.0 m/s. What can you conclude about the forces acting on the box

(A) If the force applied to the box is doubled, the constant speed of the box will increase to 8.0 m/s.
(B) The amount of force applied to move the box at a constant speed must be more than its weight.
(C) The amount of force applied to move the box at a constant speed must be equal to the amount of the frictional forces that resist its motion.
(D) The amount of force applied to move the box at a constant speed must be more than the amount of the frictional forces that resist its motion.
(E) There is a force being applied to the box to make it move but the external forces such as friction are not "real" forces they just resist motion.

29. If the force being applied to the box in the preceding problem is suddenly discontinued, the box will:

(A) stop immediately.
(B) continue at a constant speed for a very short period of time and then slow to a stop.
(C) immediately start slowing to a stop.
(D) continue at a constant velocity.
(E) increase its speed for a very short period of time, then start slowing to a stop.

9

VII. A Mechanics Baseline Test

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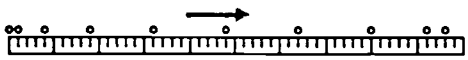
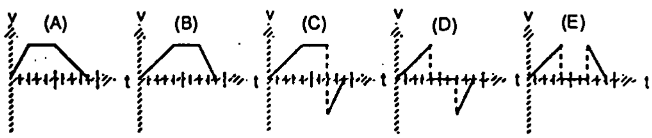
Mechanics Baseline Test

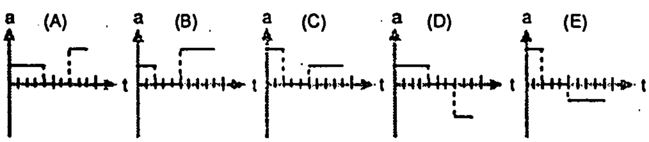
- **Refer to the diagram below when answering the first two questions. This diagram represents a multiflash photograph of an object moving along a horizontal surface. The positions as indicated in the diagram are separated by equal time intervals. The first flash occurred just as the object started to move and the last just as it came to rest.**



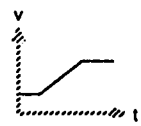
1. Which of the following graphs best represents the objects velocity as a function of time?

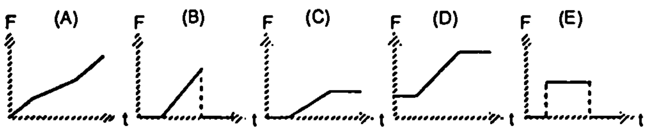


2. Which of the following graphs best represents the object's acceleration as a function of time?



3. The velocity of an object as a function of time is shown in the graph at the right. Which graph below best represents the net force-vs.-time relationship for this object?

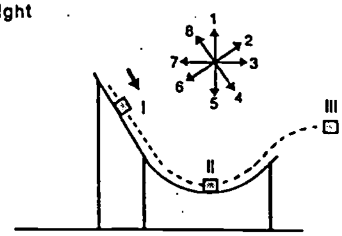




1

- **Refer to the graph on the right when answering the next three questions.**

This diagram depicts a block sliding along a frictionless ramp. The eight numbered arrows in the diagram represent directions to be referred to when answering the questions.



4. The direction of the acceleration of the block, when in position I, is best represented by which of the arrows in the diagram?

   (A) 1 (B) 2 (C) 4 (D) 5
   (E) None of the arrows, the acceleration is zero.

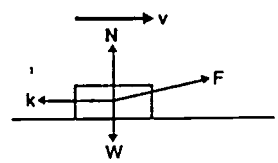
5. The direction of the acceleration of the block when in position II is best represented by which of the arrows in the diagram?

   (A) 1 (B) 3 (C) 5 (D) 7
   (E) None of the arrows, the acceleration is zero.

6. The direction of the acceleration of the block (after leaving the ramp) at position III is best represented by which of the arrows in the diagram?

   (A) 2 (B) 3 (C) 5 (D) 6
   (E) None of the arrows, the acceleration is zero.

7. A person pulls a block across a rough horizontal surface at a constant speed by applying a force F. The arrows in the diagram correctly indicate the directions, but not necessarily the magnitudes of the various forces on the block. Which of the following relations among the force magnitudes W, k, N, and F must be true?



   (A) F = k and N = W (B) F = k and N > W
   (C) F > k and N < W (D) F > k and N = W
   (E) None of the above choices

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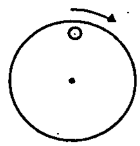
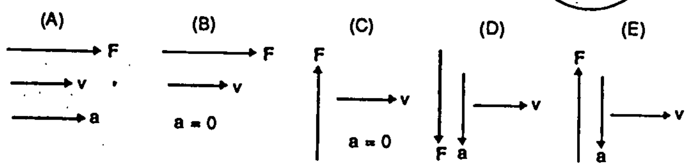
8. A small metal cylinder rests on a circular turntable, rotating at a constant speed as illustrated in the diagram at the right. Which of the following sets of vectors best describes the velocity, acceleration, and net force acting on the cylinder at the point indicated in the diagram?

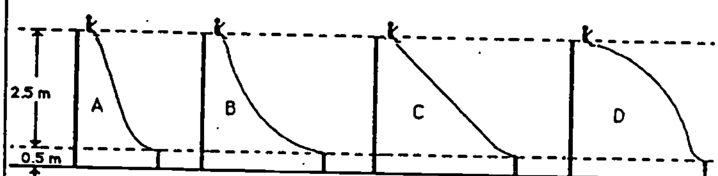




9. Suppose that the metal cylinder in the last problem has a mass of 0.10 kg and that the coefficient of static friction between the surface and the cylinder is 0.12. If the cylinder is 0.20 m from the center of the turntable, what is the maximum speed that the cylinder can move along its circular path without slipping off of the turntable?

(A) $0 < v \leq 0.5$ m/s
(B) $0.5 < v \leq 1.0$ m/s
(C) $1.0 < v \leq 1.5$ m/s
(D) $1.5 < v \leq 2.0$ m/s
(E) $2.0 < v \leq 2.5$ m/s

10. A young girl wishes to select one of the frictionless playground slides illustrated below to give her the greatest possible speed when she reaches the bottom of the slide.



Which of the slides illustrated in the diagram above should she choose?

(A) A (B) B (C) C (D) D
(E) It doesn't matter, her speed would be the same for each.

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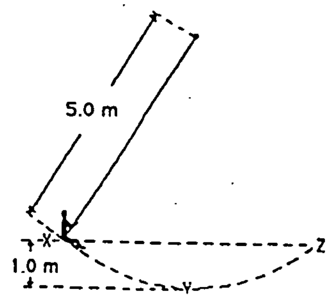
- Refer to the diagram below when answering the next two questions.

X and Z mark the highest and Y the lowest positions of a 50.0 kg boy swinging as illustrated in the diagram to the right.



11. What is the boy's speed at point Y?

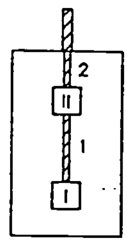
(A) 2.5 m/s (B) 7.5 m/s
(C) 10. m/s (D) 12.5 m/s
(E) None of the above.

12. What is the tension in the rope at point Y?

(A) 250 N (B) 525 N (C) 7×10^2 N (D) 1.1×10^3 N
(E) None of the above.

- Refer to the diagram below when answering the next two questions.

Blocks I and II, each with a mass of 1.0 kg are hung from the ceiling of an elevator by ropes 1 and 2.



13. What is the force exerted by rope 1 on block I when the elevator is traveling upward at a constant speed of 2.0 m/s?

(A) 2 N (B) 10 N (C) 12 N
(D) 20 N (E) 22 N

14. What is the force exerted by rope 1 on block II when the elevator is stationary?

(A) 2 N (B) 10 N (C) 12 N (D) 20 N (E) 22 N

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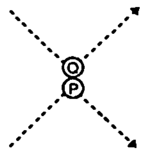
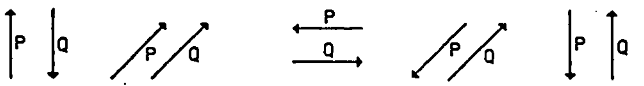
• Refer to the following diagram when answering the next two questions.

The diagram to the right depicts the paths of two colliding steel balls, P and Q.



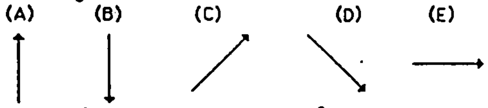
15. Which set of arrows best represents the direction of the change in momentum of each ball?

(A) (B) (C) (D) (E)



16. Which arrow best represents the direction of the impulse applied to ball Q by ball P during the collision?

(A) (B) (C) (D) (E)



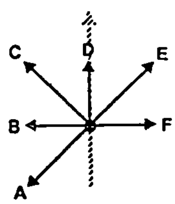
17. A car has a maximum acceleration of 3.0 m/s^2. What would its maximum acceleration be while towing a second car twice its mass?

(A) 2.5 m/s^2 (B) 2.0 m/s^2 (C) 1.5 m/s^2
(D) 1.0 m/s^2 (E) 0.5 m/s^2

18. A woman weighing 6.0×10^2 N is riding an elevator from the 1st to the 6th floor. As the elevator approaches the 6th floor, it decreases its upward speed from 8.0 to 2.0 m/s in 3.0 s. What is the average force exerted by the elevator floor on the woman during this 3.0 s interval?

(A) 120 N (B) 480 N (C) 600 N
(D) 720 N (E) 1200 N

19. The diagram at the right depicts a hockey puck moving across a horizontal, frictionless surface in the direction of the dashed arrow. A constant force F, shown in the diagram, is acting on the puck. For the puck to experience a net force in the direction of the dashed arrow, another force must be acting in which of the directions labeled A, B, C, D, E?



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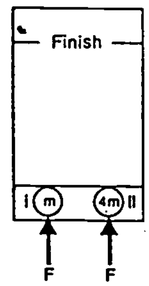
• Refer to the diagram below when answering the next three questions

The diagram depicts two pucks on a frictionless table. Puck II is four times as massive as puck I. Starting from rest, the pucks are pushed across the table by two equal forces.



20. Which puck will have the greater kinetic energy upon reaching the finish line?

(A) I (B) II
(C) They both have the same amount.
(D) Too little information to answer.

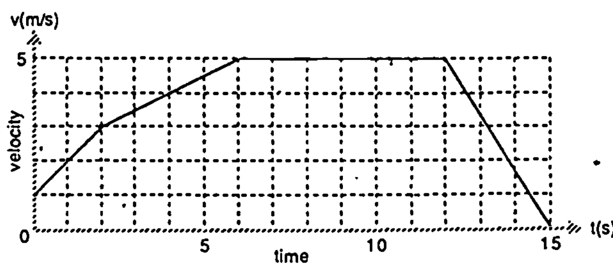
21. Which puck will reach the finish line first?

(A) I (B) II
(C) They will both reach the finish line at the same time.
(D) Too little information to answer.

22. Which puck will have the greater momentum upon reaching the finish line?

(A) I (B) II
(C) They will both have the same momentum.
(D) Too little information to answer.

• Refer to the following kinematical graph when answering the next three questions.



The graph represents the motion of an object moving in one dimension.

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23. What was the objects average acceleration between t = 0 s and t = 6.0 s?

(A) 3.0 m/s² (B) 1.5 m/s² (C) 0.83 m/s² (D) 0.67 m/s²
(E) None of the above.

24. How far did the object travel between t = 0 and t = 6.0 s?

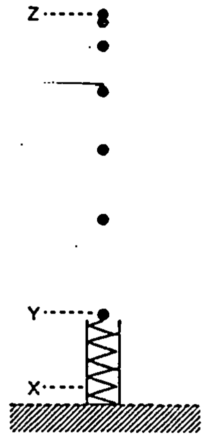
(A) 20. m (B) 8.0 m (C) 6.0 m (D) 1.5 m
(E) None of the above.

25. What was the average speed of the object for the first 6.0 s?

(A) 3.3 m/s (B) 3.0 m/s (C) 1.8 m/s (D) 1.3 m/s
(E) None of the above.

- **Refer to the diagram in the right margin to answer the following question.**

The figure represents a multiflash photograph of a small ball being shot straight up by a spring. The spring, with the ball atop, was initially compressed to the point marked X and released. The ball left the spring at the point marked Y, reaches its highest point at the point marked Z.



26. Assuming that the air resistance was negligible;

(A) The acceleration of the ball was greatest just before it reached point Y (still in contact with the spring).
(B) The acceleration of the ball was decreasing on its way from point Y to point Z.
(C) The acceleration of the ball was zero at point Z.
(D) All of the above responses are correct.
(E) The acceleration of the ball was the same for all points in its trajectory from points Y to Z.

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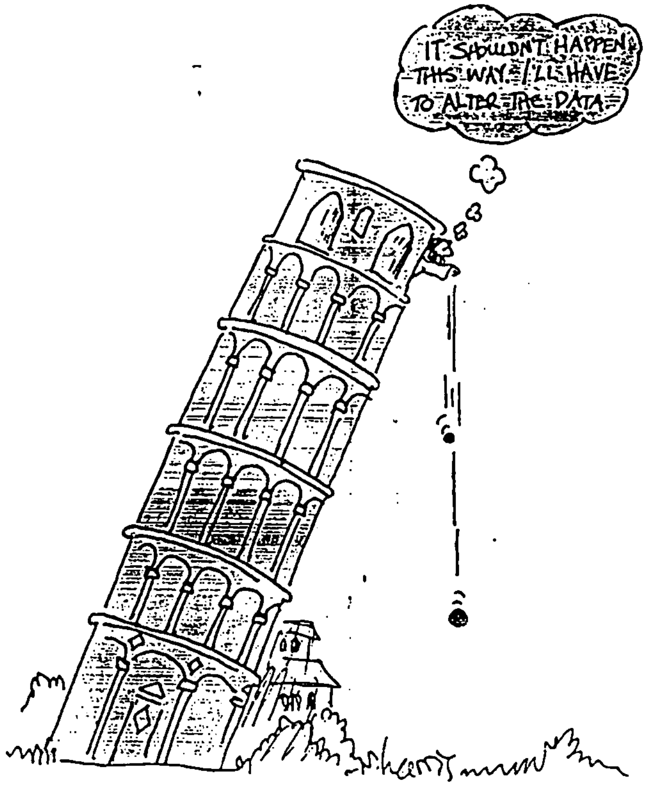

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