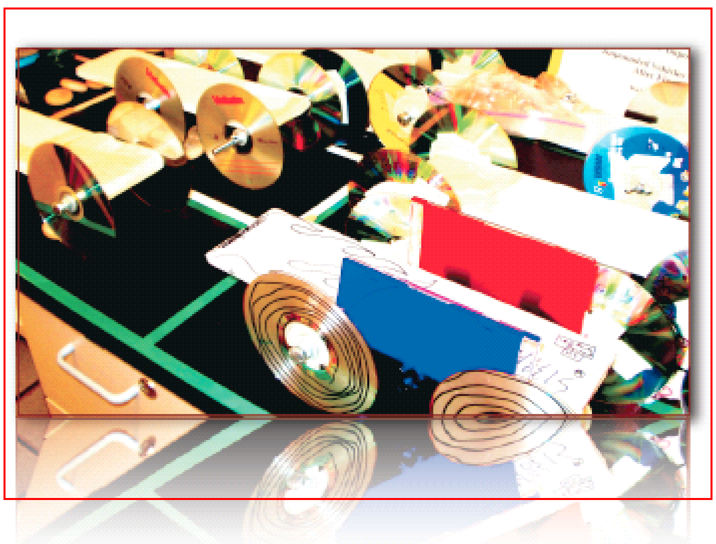
# VOLUME II

PROMOTING CONCEPTUAL CHANGE IN PHYSICS USING

# *models*

VOLUME II



PAREA REPORT 2007 PA2005-010

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# INTRODUCTION

## Overview

Both researchers and teachers have reported that although students in introductory college courses demonstrate mastery in solving quantitative physics problems, they perform very poorly when asked to answer questions reflecting their conceptual understanding of mechanics. That is, they appear to solve the numerical physics problems by applying formulae by rote. However, the assumption that students understand a topic such as mechanics on the basis of their ability to solve (by rote) problems, not only is faulty but obscures the specific problems they may have with some of the underlying or prerequisite concepts. Much of the research being carried out to develop human and computer-mediated tutoring systems in physics, for example Andes (Wintersgill, 2005) depends on developing a model of how students solve typical problems in the domain (i.e., a "student model"). Several instruments, e.g., the Force Concept Inventory (FCI) have been designed to measure such student models of mechanics. The research in this volume describes our attempt to use the FCI to elicit some of the details of such a model and to identify some of the student characteristics that modify students' response on the FCI.

## Research Questions

We addressed the following research questions in Volume II:

1. How well do students understand the basic concepts underlying Newtonian physics at the end of a one-semester college course in mechanics (as measured by the FCI)?
2. What correlations are there among students' scores on the FCI, student characteristics (high school grades, reading comprehension scores, etc), formal reasoning and document literacy?
3. What recommendations can we draw from our findings to improve college physics instruction and research?

# THEORETICAL BACKGROUND

## Document Literacy

Science students are expected to interpret and reason information presented as tables, graphs, and flow charts in many of their science courses. These are cognitively complex skills, involving interactions among three factors: the cognitive skills of the student, the properties of the graphical representation, and the task demands (Peebles & Cheng, 2003). In most science courses, students are exposed to a variety of graphical representations, but are rarely explicitly taught the underlying structure of such representations.

The recent advances in graphical technologies have stimulated interest in how students and adults extract information from such external representations (Scaife & Rogers, 1996). Moreover, several instruments (ALLS, IALS, TOWES) measuring document literacy (i.e., the knowledge and skills required by adults to locate and use information from complex documents containing graphical representations such as tables, maps, diagrams, and flow charts) have been developed. In the process of developing these instruments, a model of how students process tabular and graphical information has been developed (Mosenthal & Kirsch, 1991, Kirsch, 2001). Such models, not only help researchers and teachers develop better test items, they also help us understand the mistakes students make in answering questions involving pictures and graphs and ultimately teach better.

At the beginning of this research project we conducted a pilot study (d'Apollonia, 2006) to determine whether the TOWES (TOWES 2004) could be used to measure science students' document literacy level. We found that most of the science students had surprisingly low levels of document literacy. More than 90% of the students were only at level 2, indicating that they could only deal with graphical representations which were clear, simple, and/or explicitly described. Although these students have adapted their literacy skills to everyday life, they would have great difficulty with many of the reading tasks found in university science courses or in jobs requiring science degrees. Interviews with the students suggest that many students have only a superficial understanding of tables and graphs and have difficulty following instructions. However, an alternative possibility was that students were not motivated to complete the everyday tasks imbedded in the TOWES.

We therefore constructed an alternative test to the TOWES using tasks that are similar to those described in science textbooks. This test of document literacy is presented in Appendix 1 of this volume. Since, many of the questions on the FCI include diagrams, we decided to investigate thre influence of document literacy on students' performance on the FCI.

## Force Concept Inventory

One of the most active areas in science education is in the area of physics education. This is in large part due to the development of diagnostic instruments designed to capture students' mental models of Newtonian concepts and their validation across a large number of students, classes, and institutions. This instruments include the Mechanics Diagnostic Test (MDT) developed by Halloun and Hestenes (1985), the Force Concept Inventory (FCI) developed by Hestenes, Wells, and Swackhammer (1992), and the Tools for Scientific Thinking: Force and Motion Conceptual Evaluation (TST developed by Thornton (Thornton, 1995;1997).

The *Force Concept Inventory* is the most widely used and validated diagnostic test in physics (Hestenes, Wells, and Swackhamer, 1992; Hake 1998). It was originally published in 1992 but revised by Ibraham Halloun, Richard Hake, Eugene Mosca, and David Hestenes in 1995; this revision is the version used in this study and is presented in Appendix 1. The FCI has 30 items, dealing with the six Newtonian concept of force. It was designed with strong distracters eliciting the "commonsense" notions of students about motion. It is currently being used to develop "student models" of learning mechanics both for the development of standardized test items (Cromley & Mislevy, 2005) and in the design of an intelligent tutoring system, for example Andes (Wintersgill, 2005).

## Formal Reasoning

Piaget (1972) theorized that learners acquire a set of four operations (INRC) constituting the structure of reasoning between the ages of 11 and 15. Inhelder and Piaget (1958) defines formal reasoning to include the following nine reasoning skills: hypothetical reasoning (predicting possible outcomes); deductive reasoning (reasoning from general rule to specific instance) proportional reasoning (reasoning about relationships in form x/y = a/b); combinatorial reasoning (generating a list of all possible combinations of three or more variables); holding one variable constant (establishing a trial procedure to isolate the effects of one factor); correlational analysis (determining whether two events covary); probabilistic reasoning estimating the probability that a given event will occur); propositional, verbal, or symbolic reasoning (reasoning about relationships); complex problem solving (generalizations to a new context). Five of the above formal reasoning skills have been identified as being essential for success in science and mathematics (Bitner, 1991). These are proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning.

The Arlin Test of Formal Reading (ATFR) is a 32 item pencil and paper test developed by Patricia Arlin (Arlin, 198, 1984 ) to assess students' ability to complete the tasks employed by Inhelder and Piaget (1958). That is, they were designed to assess students' reasoning about the Multiplicative compensations, Correlations, Probability, Combinations, Proportions, Forms of conservation beyond direct verification, Mechanical equilibrium, and The coordination of multiple frames of reference. The test can be used to score students overall formal reasoning performance as well as their developmental stage (Low Concrete, High Concrete, Transitional, Low Formal, and High Formal).

In a previous study, d'Apollonia, (2005) of formal reasoning we found that 77% of Pre-university science students at least a Low Formal level of formal reasoning. Moreover, there were gender effects with female students significantly less skilled than male students at proportional reasoning. Since Colletta, Philips, and Steinert (2007) have shown that abstract (formal) reasoning was strongly correlated to students' score on the FCI, we decided to include a measure of formal reasoning in this study.

# RESEARCH DESIGN AND METHODOLOGY

## Document Literacy

We developed a science-specific test of document literacy consisting of 8 questions. The test included both tables and graphs and covered topics taken from science text books. We are in the process of investigating the properties of this test (reliability, validity, etc.). The test is presented in Appendix 1. To obtain a description of the test properties of this questionnaire please contact one of the authors.

## FCI Questionnaire

Because of classroom time constraints, we were not able to give students the complete 30 item test both at the pretest and the posttest. Therefore we selected 20 questions from the complete tests for the abridged FCI pretest and 21 items for the abridged FCI posttest. Ten questions were common to both instruments. Thirty eight students took the complete FCI. We subsequently analyzed the students' responses, calculating their scores over the three versions of the test. The correlation between the complete FCI and the abridged FCI pretest and abridged FCI posttest were .99 and .98, respectively.

## Formal Reasoning

We prepared an abridged version of the Arlin Test of Formal Reasoning (ATFR) from Slossan Educational Publications, Inc. (Arlin, 1982, 1984) by selecting the 16 that measure the following four subskills of formal reasoning:

a) **Multiplicative Compensations:** Reasoning about effects of two or more variables that have an inverse relationship. That is gains or losses in one variable are compensated by gains or losses in **the other.**

**b) Forms of conservation beyond direct verification**: Reasoning about the influence of one variable on a second which is not directly observable but must be inferred

c) **Mechanical equilibrium**: Reasoning simultaneously about the influence of many coordinated variables that affect equilibrium processes.

d) The **coordination of multiple frames of reference** :Reasoning about the coordination of two related systems, each involving a direct and an inverse operation. It represents a type of relativity of thought.

The questionnaire that the students completed is presented in Appendix 1.

## Data Analysis

Multivariate statistical tests were used using the SPSS (Version 11.5) General Linear Model to compare students' responses on the FCI (MANOVA) as well as to compare their responses befor and after instruction (Repeated Measures).

# Results and Discussion

## Student Performance on Force Concept Inventory

Two hundred and forty eight students wrote an abridged Force Concert Inventory both at the beginning and the end of a college introductory mechanics course. The frequency distributions of their scores on the pretest and posttest, shown in Figure 1, indicate that the students' scores on the pretest are normally distributed and relatively uniformly low. However, after instruction, the students' scores are widely spread out indicating that not all students benefit **equally** from instruction.

Hestenes and Halloun (1997) have interpreted the FCI scores as providing evidence for a three stage model of conceptual understanding of Newtonian mechanics. They state that scores below 60% indicate students are at a Stage I (below the threshold required to begin developing Newtonian ideas), scores between 60 % and 80% are at a Stage II (pre-Newtonian stage in conceptual understanding of force and motion), and score above 80% are at Stage III (mastery of the Newtonian force concept).

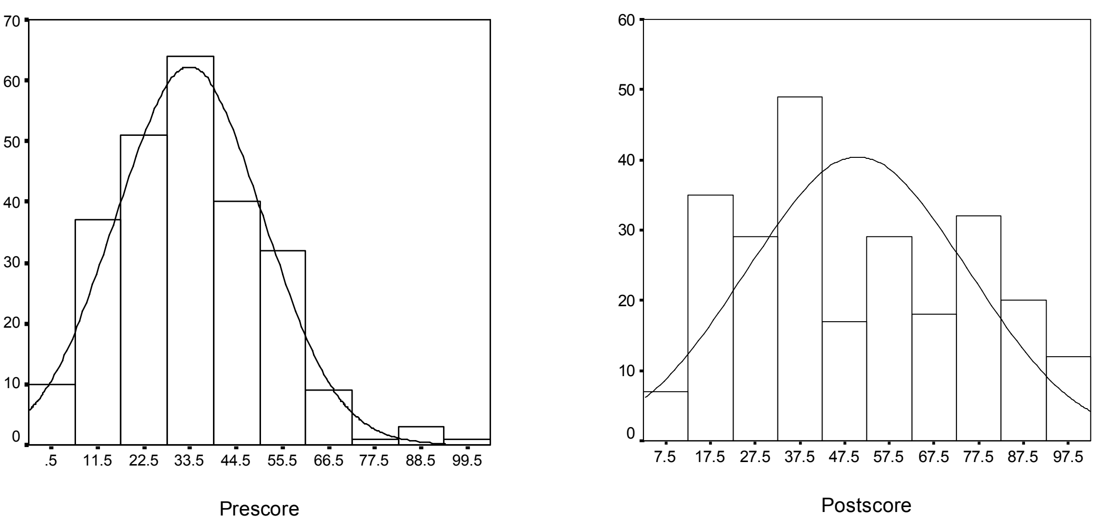



**Figure 1**. Distribution of students' scores on the abridged FCI (N= 248) pretest and posttest.

Table 1 shows the mean performance for 248 students on the abridged FCI and indicates that although students increased their conceptual understanding of mechanics after instruction, on average they still remained at a Stage I or pre-Newtonian stage of conceptual understanding . That is, they have a fragmented and incoherent understanding of force and motion even after taking a college course in mechanics. As indicated in Figure 1, more than 50% of the students still lack a vectorial concept of velocity; do not distinguish among velocity, position, and acceleration, believe that there are additional influences on motion, besides force (i.e., impetus), and misidentify active and passive agents of force.

Table 1. Student performance on abridged FCI (N = 248).

| FCI | Mean | SD |
|---|---|---|
| pretest | 33.3 | 17.5 |
| posttest | 50.4 | 24.4 |

## Influence of Student Characteristics on Performance on the Abridged FCI

We subsequently explored some of the student characteristics that might explain the variability in students' performance on the abridged FCI both before and after instruction. Table 2 shows the correlations between the students' scores on the abridged FCI tests and English proficiency (score on Nelson-Denny), grades on high school prerequisite chemistry, physics, and mathematics courses, gender, formal reasoning and document literacy. Document literacy, English proficiency, gender, and grades on the high-school prerequisite math and science courses are associated with conceptual understanding of forces and motion on both tests.

Table 2. Correlations (Pearson Product) between posttest score on the abridged FCI and student characteristics.

| Student Characteristic | Pretest | Posttest |
|---|---|---|
| Gender | .40* | .46* |
| English Proficiency | .45* | .36* |
| Chemistry | .37* | .54* |
| Physics | .46* | .67* |
| Mathematics | .34* | .60* |
| Formal Reasoning | .25 | .21 |
| Document Literacy | .48* | .39* |

* significant at $p < .05$.

We subsequently investigated the degree to which the above characteristics predicted students' scores on the abridged FCI. When the above six variables were entered into a linear multiple regression model, 57% and 66% of the variability in pretest and posttest FCI scores, respectively were predicted. Table 3 shows the standardized Beta values for each variable and indicates that gender and English proficiency predict performance on both the pretest and posttest. In addition, document literacy also predicts performance on the pretest.

Table 3. Standardized Beta coefficient for student characteristics as predictors of achievement on the abridged FCI.

| Student Characteristic | Pretest | Postest |
|---|---|---|
| Document Literacy | .26* | .06 |
| Gender | .32* | .53* |
| English Proficiency | .49* | .26* |
| Physics | .13 | .24 |
| Mathematics | -.16 | .11 |
| Chemistry | .27 | .09 |

* significant at $p < .05$.

This suggests that performance on the FCI is dependent on literacy (whether general reading ability or the ability to read tables and graphs). Several researchers (Lemke, 1990, Touger, 1991, Itza-Ortiz, Rebello, Zollman, and Rodriguez-Achach,2003) have suggested that the difficulties that students have with concepts in physics, lies in their difficulties with the "language of physics". For example, Brookes and Etkina (2007) have shown that students' difficulties understanding concepts in quantum mechanics reflects their difficulties with the language of instruction (both semantic and syntactic).

We also investigated the degree to which the FCI predicts students' final grade in their introductory mechanics course. Figure 2 shows the correlation between students' scores on the FCI posttest and their final grade on their Mechanics course. Over 40% of the variability in their final grade is predicted by their FCI score. If the regression line is constrained through the origin, over 90% of the variability in students' final grade is predicted. This suggests that the final course grade in the introductory physics course reflects other factors besides conceptual understanding, especially for students at the lower grades.

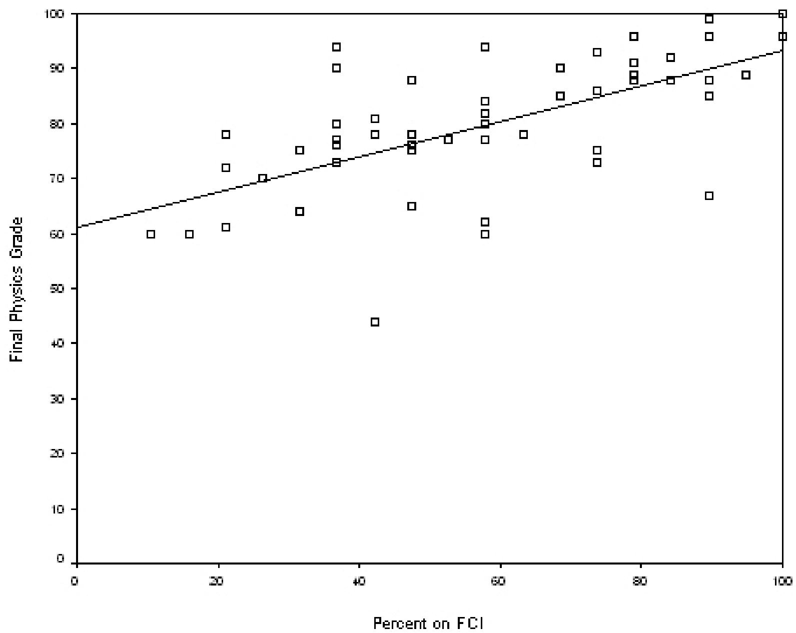


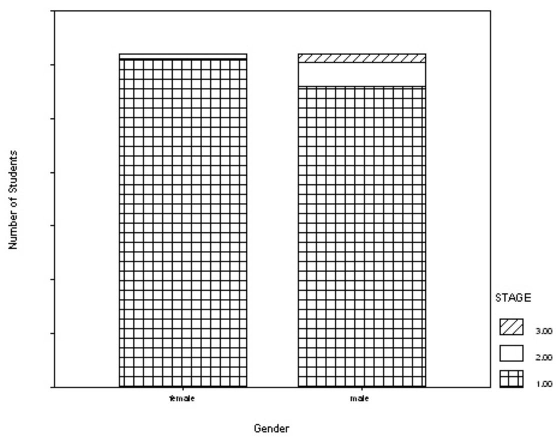

Figure 2. Predictability of final physics course grade by posttest score on FCI.

## Influence of Gender on Performance on the Abridged FCI

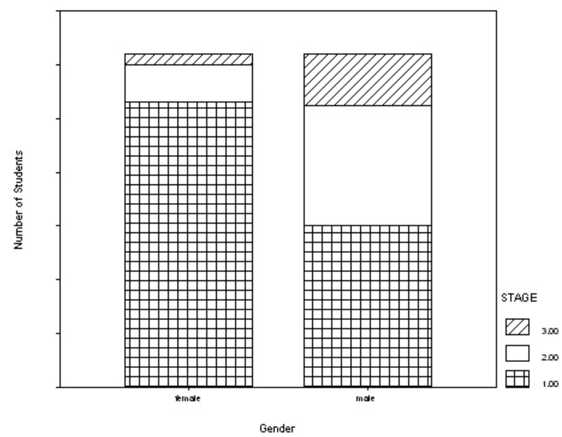
Since gender was a good predictor of performance on both the abridged FCI, we investigated its influence on students' conceptual understanding of forces and motion. Table 4 and Figure 3 show the distribution of female and male students into the three stages of conceptual understanding of forces and motion. They indicate that at the beginning of a college introductory mechanics course almost all female students (98.4%) are at Stage I of Newtonian thinking (that is, they are below the threshold of pre-Newtonian conceptual understanding of force and motion) compared to 90.3% of the male students. While 37.5% of male students who were classified as Stage I on the pretest shifted to Stage II and 9.8% shifted to Stage III, only 10.7 % and 2.4% of the female students shifted to Stage II and Stage III respectively.

Table 4. Influence of gender on Distribution of students in each stage of conceptual understanding of force and motion. (N=248).

| Stage | All Students | | Female Students (N=124) | | Male Students (N=124) | |
|---|---|---|---|---|---|---|
| | pretest | posttest | pretest | posttest | pretest | posttest |
| I | 94.4 | 66.9 | 98.4 | 85.5 | 90.3 | 48.4 |
| II | 4.4 | 23.8 | 1.6 | 11.3 | 7.3 | 36.3 |
| III | 1.2 | 9.3 | 0 | 3.2 | 2.4 | 15.3 |




(a)




(b)

Figure 3. Distribution of female and male students into stages I, II, and III of conceptual understanding of Newtonian mechanics on the FCI pretest (a) and the posttest (b).

However, there were no significant differences in male and female students' performance on the first semester physics, math, and chemistry courses. Thus, the abridged FCI may be differentiating between students' underlying conceptual understanding of force and their ability to pass their first semester physics course.

McCullough (2000, 2002, 2006) has been conducting a series of studies on the role of context on the differences in scores on the FCI for male and female students. In general, she has found that the "gender gap" is between 5% and 25% in favour of male students. She has produced an instrument were the questions were "gender neutral" and investigated how female and male students perform on this version. She (and others) have found that changing the context causes the scores on different questions to vary greatly. However, there is no consistent pattern. However, pedagogies that promote more active engagement reduce the "gender gap".

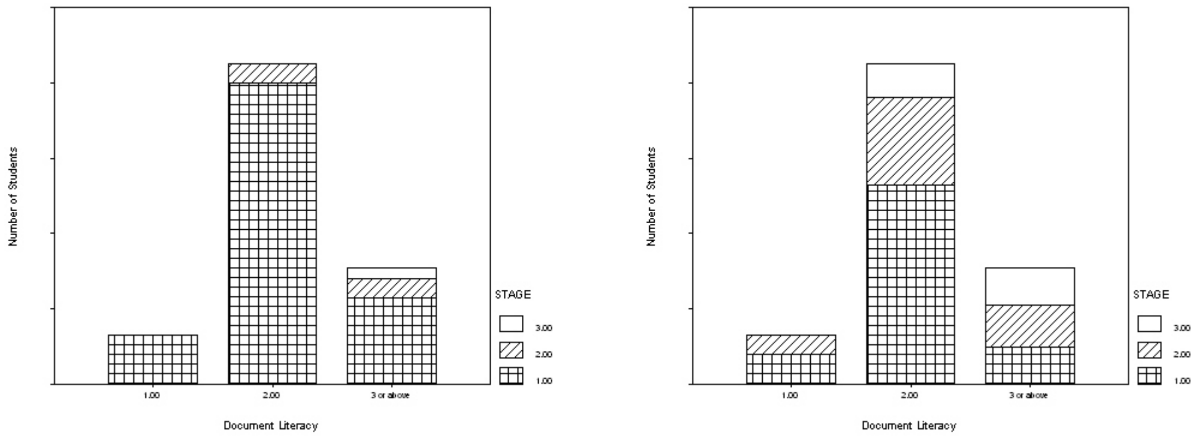
## Influence of Document Literacy on Performance on the Abridged FCI

Since document literacy was a good predictor of performance on the abridged FCI, we investigated its influence on students' conceptual understanding of forces and motion. Table 5 and Figure 4 show the distribution of students at three stages of document literacy into the three stages of conceptual understanding of forces and motion. They indicate that at the beginning of a college introductory mechanics course, students' performance is affected significantly by their ability to interpret the diagrams. However, during as they progress through the mechanics course, they acquire these skills so that document literacy does not influence their performance on the posttest.

Table 5. Influence of document literacy on the distribution of students in each stage of conceptual understanding of force and motion.

| Stage | Document Literacy Stage | | | | | |
|---|---|---|---|---|---|---|
| | 1<br>N=13 | | 2<br>N=85 | | 3 or greater<br>N=31 | |
| | pretest | posttest | pretest | posttest | pretest | posttest |
| I | 100 | 61.5 | 80 | 62.4 | 74.2 | 32.3 |
| II | 0 | 38.5 | 5.9 | 27.1 | 16.1 | 35.5 |
| III | 0 | 0 | 0 | 10.6 | 9.7 | 32.3 |

All students with a document literacy level of 1 are at Stage 1 of Newtonian conceptual understanding. After the introductory course in mechanics only 38.5% of these students proceed to a Stage II understanding with 0% reaching a Stage III. Eighty percent of students with a document literacy level of 2 are at Stage 1 of Newtonian conceptual understanding. After the introductory course in mechanics, the percentage of students that have achieved a Stage II and III stage of Newtonian conceptual understanding has increased to 27.1% and 10.6%, respectively. Although there are about the same percentage of students with a document literacy level of 3 at Stage 1 of Newtonian conceptual understanding (74.2%), more of these students have achieved a conceptual understanding of forces and motion, with 35.5% and 32.3% achieving a Stage II and Stage III level of conceptual understanding.




**(a)** **(b)**

Figure 4. Distribution of students at 3 levels of document literacy ceptual understanding of Newtonian mechanics on the FCI pretest (a) and the posttest (b).

This suggests that students must have at least a rudimentary ability to extract meaning from tables and graphs (i.e., level 2 on document literacy) to answer the questions correctly on the FCI. When students enter an introductory college mechanics course they are not familiar with some of the graphing conventions used in physics. As they are exposed to them, they acquire the skill and thus their performance on the FCI posttest is less dependent on document literacy.

## Influence of Program of Entry and Gender on Performance on the Abridged FCI

High school grades are used to place students into different college science programs: an honours science program for students with high (> 90%) science and mathematics high school grades, a regular science program for students with grades > 70%, and a preparatory science program for students who either did not have the required science and mathematics prerequisite courses or who had low grades in these courses (> 60% and < 70%). Thus, we subsequently explored the influence of program of entry on students' performance on the FCI.

Table 6 shows the means and 95% confidence intervals on the abridged Force Concert Inventory (pretest, posttest, and Hake scores[1]) for female and male students in the three programs. It indicates that

[1] Hake (1998) defined the normalized gain as the change in score divided by the maximum possible increase. $G = (\text{postscore}\% - \text{prescore}\%)/(100\% - \text{prescore}\%)$.

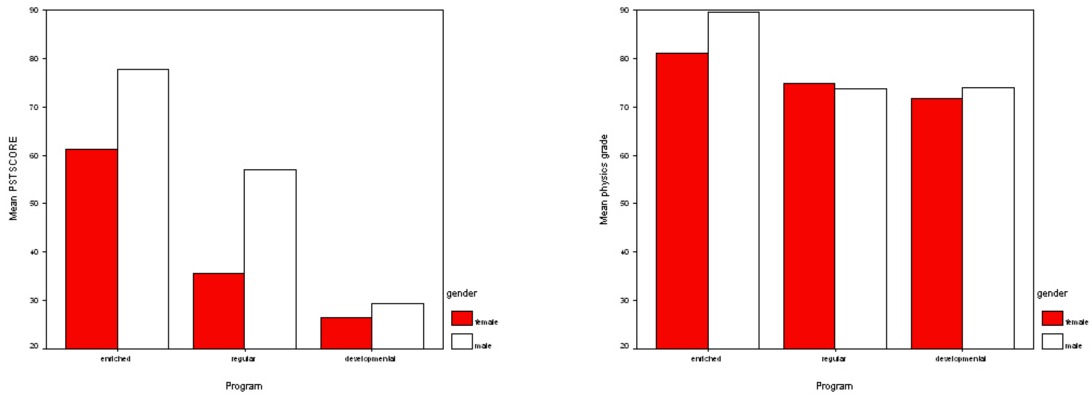
male students in the honours and regular science programs outperformed female students on the pretest and the posttest. It also indicates that while both male and female students in the honours program achieve at least a stage II understanding of force, only male students in the regular program acquire this level of understanding of force.

Hake (1998) carried out a comparison of the performance of over 6000 students in 62 introductory physics classes in which the FCI was used to measure conceptual understanding of forces and motion. The classes were classified into either *active engagement* or *traditional*. Hake concluded that a Hake score (the class normalized gain) of 0.23 ± .04 characterized classes which were *traditional* compared to a Hake score of 0.48 ± .14 for classes categorized as *active engagement.* Hake and others (Redish, Saul, & Steinberg, 1997) argue that teaching methods (traditional versus those using pedagogies promoting active engagement) are responsible for the differences in students' conceptual understanding. Cummings, Marx, Thornton, and Kuhl (1999) argue that it is the quality of cognitive engagement and not the interactivity *per se* that causes the gains in student understanding. The results here support the view that individual differences in the way students approach learning physics can also be responsible for the gains in conceptual understanding. The Hake scores for the students in honours physics classes is very similar to that for classes using *active engagement* pedagogies; however, these classes differed from the regular classes not in pedagogy but rather in student abilities. Students' in the honours classes are much more demanding and engaged in their learning. They question the instructor continually and insist on understanding the material.

Figure 5 compares the students' performance by gender within each program on the FCI posttest to their performance in their mechanics physics course. It indicates that the FCI is differentiating between students' underlying conceptual understanding of force and their performance in their mechanics course. It appears that although female students in the regular science program are performing as well as their male peers in the mechanics course, they are not acquiring the conceptual understanding of force to the same degree. As discussed previously, although the gender gap may reflect in part problems with the FCI, it also reflects differences in motivation and conceptual understanding of physics.

Table 6. Student performance on abridged FCI as a function of program of entry and gender.

| Score | Program | Gender | Number | Mean | 95% Confidence Interval |
|---|---|---|---|---|---|
| Pretest | Honours | female | 27 | 36.1 | 30.7 to 41.5 |
| | | male | 43 | 50.2 | 45.9 to 54.5 |
| | Regular | female | 71 | 25.6 | 22.2 to 28.9 |
| | | male | 69 | 36.5 | 34.1 to 40.9 |
| | Preparatory | female | 26 | 18.7 | 13.1 to 24.2 |
| | | male | 12 | 20.0 | 11.9 to 28.1 |
| posttest | Honours | female | 27 | 62.1 | 54.6 to 67.8 |
| | | male | 43 | 76.8 | 72.5 to 83.0 |
| | Regular | female | 71 | 35.6 | 31.5 to 39.7 |
| | | male | 69 | 57.0 | 52.9 to 61.1 |
| | Preparatory | female | 26 | 21.6 | 19.8 to 33.3 |
| | | male | 12 | 29.9 | 19.5 to 39.3 |
| Hake | Honours | female | 27 | 0.40 | 0.3 to .5 |
| | | male | 43 | 0.55 | 0.5 to .6 |
| | Regular | female | 71 | 0.15 | 0.1 to .2 |
| | | male | 69 | 0.35 | 0.3 to .4 |
| | Preparatory | female | 26 | 0.10 | 0.0 to .2 |
| | | male | 12 | 0.20 | 0.1 to .3 |




FCI Posttest Mechanics Course Grade

Figure 5. Student performance on abridged FCI posttest (a) and mechanics course (b) as a function of program of entry and gender.

## Student Understanding about Newtonian Concepts

One of the goals of this research project was to explore the degree to which the FCI measures changes in students' understanding of Newtonian concepts over a semester course in mechanics. Thus, we present the results on the pretest and the posttest separately for female and male students in the honours, regular, and preparatory programs in Tables 7, 8, 9, and 10. We subsequently explored students' responses on the abridged FCI for the questions that were included on both the pretest and posttest. In general, the students in the honours, regular, and preparatory programs improved on 8, 7, and 3 of the 10 questions, respectively. There were **no significant effects** of gender on the improvement in conceptual understanding of forces and motion. These results are summarized in Table 11 and subsequently discussed under each Newtonian topic.

Table 7. Significant[1] Differences in the Performance of Students in the honours, regular, and preparatory Programs on the Abridged Pretest. Shaded entries indicate that there were no significant differences.

| Topic | Subtopic | Q | Percent Correct Responses per Program on Pretest | | | sig dif* |
|---|---|---|---|---|---|---|
| | | | Enhanced N=71 | Regular N=174 | Developmental N=42 | |
| Kinematics | Position | 19 | 56 | 34 | 17 | all |
| | Acceleration | 20 | 66 | 28 | 10 | all |
| Forces | Gravity | 1 | 88 | 49 | 38 | all |
| | | 2 | 49 | 35 | 19 | (e,d)(r,d) |
| | | 12 | 70 | 47 | 29 | all |
| | | 13 | 23 | 5 | 2 | (e,r)(e,d) |
| | Friction | 27 | 59 | 40 | 33 | (e,d) |
| | | 29 | | 39 | | |
| First Law | No Force | 5 | | 7 | | |
| | | 7 | | 29 | | |
| | | 8 | 51 | 31 | 21 | (e,d) |
| | | 10 | 54 | 23 | 14 | (e,r)(e,d) |
| | | 23 | | 12 | | |
| | Cancelling | 25 | 35 | 16 | 10 | (e,r)(e,d) |
| | | 26 | 21 | 9 | 2 | (e,r)(e,d) |
| Second Law | | 22 | 48 | 26 | 14 | (e,r)(e,d) |
| Third Law | | 4 | | 15 | | |
| | | 11 | | 5 | | |
| | | 15 | | 12 | | |
| | | 16 | | 36 | | |

[1] There are significant differences (F=1.72, df=238,2, p=.001) among the performances of students in the three programs.
* results of Post hoc tests indicating which contrasts were significantly different

Table 8. Significant differences in Female and Male performance on the abridged FCI Pretest. Shaded entries indicate that there were no significant differences.

| Topic | Subtopic | Q | Percent Correct Responses by on Pretest by Gender | |
|---|---|---|---|---|
| | | | Female N=145 | Male N=142 |
| Kinematics | Position | 19 | 37 | |
| | Acceleration | 20 | 34 | |
| Forces | Gravity | 1 | 57 | |
| | | 2 | 36 | |
| | | 12 | 37 | 62 |
| | | 13 | 3 | 16 |
| | Friction | 27 | 44 | |
| | | 29 | 39 | |
| First Law | No Force | 5 | 2 | 10 |
| | | 7 | 43 | |
| | | 8 | 26 | 39 |
| | | 10 | 23 | 37 |
| | | 23 | 13 | 28 |
| | Cancelling | 25 | 20 | |
| | | 26 | 4 | 17 |
| | | 11 | 5 | 18 |
| Second Law | | 22 | 30 | |
| Third Law | | 4 | 15 | |
| | | 15 | 13 | |
| | | 16 | 36 | |

[1] There are significant differences (F=2.14, df=238,1, p=.004) between the performances of female and male students.

Table 9. Significant[1] differences in the performance of students in the Honours, Regular, and Preparatory programs on the abridged FCI Posttest. Shaded entries indicate that there were no significant differences.

| Topic | Subtopic | Q | Percent Correct Responses by Program of Entry | | |
|---|---|---|---|---|---|
| | | | Enriched N=70 | Regular N=140 | Developmental N=38 |
| Kinematics | Vector | 14 | 80 | 66 | 26 |
| | Position | 19 | 66 | 48 | 32 |
| | Acceleration | 20 | 81 | 55 | 39 |
| Forces | Gravity | 3 | 86 | 64 | 39 |
| | | 13 | 63 | 39 | 13 |
| | | 30 | 67 | 38 | 34 |
| | Friction | 27 | 81 | 37 | 49 |
| First Law | No Force | 6 | 87 | 62 | 71 |
| | | 10 | 90 | 60 | 53 |
| | | 17 | 70 | 38 | 21 |
| | Cancelling | 25 | 69 | 34 | 05 |
| | | 26 | 53 | 22 | 03 |
| | | 11 | 69 | 36 | 24 |
| Second Law | | 9 | 54 | 29 | 29 |
| | | 21 | 47 | 35 | 13 |
| | | 22 | 50 | 41 | 16 |
| Third Law | | 16 | 90 | 51 | 29 |
| | | 28 | 81 | 55 | 39 |

[1] There are significant differences (F=5.987, df=238, 2, p=.000) among the performances of students in the three programs.

Table 10. Significant[1] differences in the performance of Female and Male students on the abridged FCI Posttest. Shaded entries indicate that there were no significant differences.

| Topic | Subtopic | Q | Percent Correct Answers on Posttest by Gender | |
|---|---|---|---|---|
| | | | Female N=145 | Male N=142 |
| Kinematics | Vectors | 14 | 48 | 80 |
| | Position | 19 | 41 | 60 |
| | Acceleration | 20 | 60 | |
| Forces | Gravity | 3 | 52 | 80 |
| | | 13 | 30 | 53 |
| | | 30 | 46 | |
| | Friction | 27 | 45 | 69 |
| First Law | No Force | 6 | 75 | |
| | | 10 | 56 | 79 |
| | | 17 | 44 | |
| | Cancelling | 25 | 39 | |
| | | 26 | 28 | |
| | | 11 | 43 | |
| Second Law | | 9 | 26 | 47 |
| | | 21 | 23 | 47 |
| | | 22 | 25 | 55 |
| Third Law | | 16 | 48 | 69 |
| | | 28 | 38 | 66 |

There are significant differences (F=2.66, df=238,1, p=.001) between the performances of female and male students.

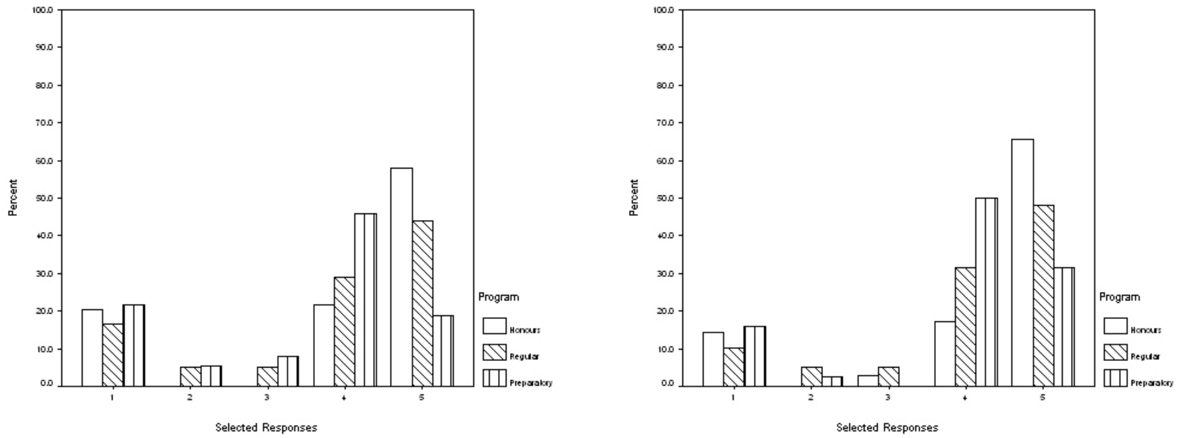
Table 11. Change in percentage of students correctly answering question.

<table>
<tr><th rowspan="2">Topic</th><th rowspan="2">Subtopic</th><th rowspan="2">Q</th><th rowspan="2">over all gain</th><th colspan="4">Percent of Students Correctly Answering Question</th></tr>
<tr><th colspan="2">Honours</th><th>Regular</th><th>Preparatory</th></tr>
<tr><td rowspan="3">Kinematics</td><td>Position</td><td>19</td><td>yes</td><td colspan="4">43% to 50%</td></tr>
<tr><td rowspan="2">Accelera-tion</td><td rowspan="2">20</td><td rowspan="2">yes</td><td>F</td><td>75%</td><td>34% to 55%</td><td>0% to 48%</td></tr>
<tr><td>M</td><td>65% to 84%</td><td>38% to 58%</td><td>29%</td></tr>
<tr><td rowspan="2">Forces</td><td>Gravity</td><td>13</td><td>yes</td><td colspan="2">23% to 63%</td><td>6% to 39%</td><td>8%</td></tr>
<tr><td>Friction</td><td>27</td><td>yes</td><td colspan="2">60% to 81%</td><td>49%</td><td>41%</td></tr>
<tr><td rowspan="4">First Law</td><td>No Force</td><td>10</td><td>yes</td><td colspan="2">54% to 90%</td><td>29% to 60%</td><td>16% to 53%</td></tr>
<tr><td rowspan="3">Canceling</td><td>25</td><td>yes</td><td colspan="2">25% to 66%</td><td>21% to 33%</td><td>8%</td></tr>
<tr><td>11</td><td>yes</td><td colspan="2">20% to 69%</td><td>11% to 36%</td><td>14%</td></tr>
<tr><td>26</td><td>yes</td><td colspan="2">22% to 54%</td><td>11% to 22%</td><td>3%</td></tr>
<tr><td colspan="2">Second Law</td><td>22</td><td colspan="5">38%</td></tr>
<tr><td colspan="2">Third Law</td><td>16</td><td>yes</td><td colspan="2">49% to 90%</td><td>45%</td><td>35%</td></tr>
</table>

## Kinematics and Forces Questions

We analyzed two questions that probed students' understanding of kinematics. Question 19 (see Appendix 1) is a measure of students' ability to distinguish between velocity and position. Question 20 (see Appendix 1) is a measure of students' ability to distinguish between velocity and acceleration.

The multivariate repeated measures test for question 19 indicates that there is a significant improvement for all students on the posttest (F=4.68, df= 234, 1 p=.03).The percentage of the students who answered this question correctly increased from 43% to 51%. Figure 6 shows that the distribution of choices students made answering question 19 did not change between the pretest and posttest. Overall students selected the same wrong answers (confusing velocity with position) on the posttest as they did on the posttest although at a lower frequency.



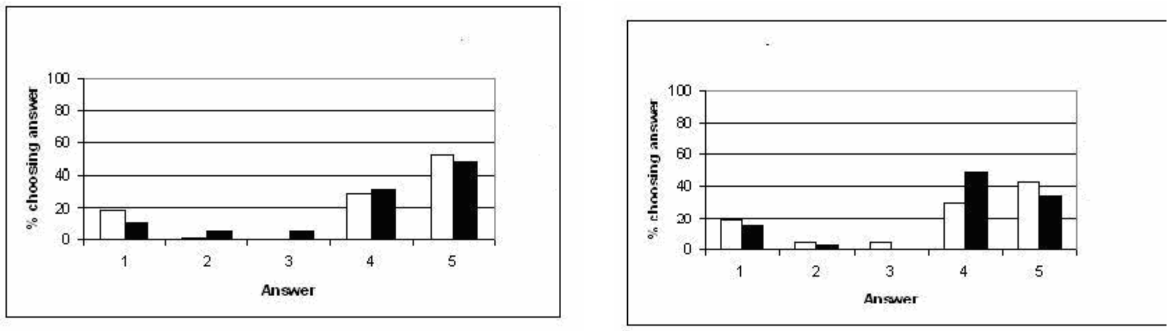

(a) pretest (b) posttest

Figure 6. Student responses on question 19 on pretest (a) and posttest (b). Correct answer is 5.

Figure 7a compares the responses of the students in the regular program **after** taking the introductory mechanics course with those of the students in the honours program **before** taking the course. Similarly, figure 7b compares the responses of the students in the preparatory program **after** taking the introductory mechanics course with those of the students in the regular program **before** taking the course. They indicate that in both cases, instruction appears to bring the pattern of responses of the less able students to that of the more able students before instruction. That is, it appears that as students learn mechanics, they pass through well defined stages of conceptual understanding. This in part reflects the construction of the FCI which was designed to capture the common misconceptions made by students when they were interviewed on their responses to the FCI (Adams, & Slater, 2003, Huffman & Heller, 1995, Steinberg & Sabella, 1997)

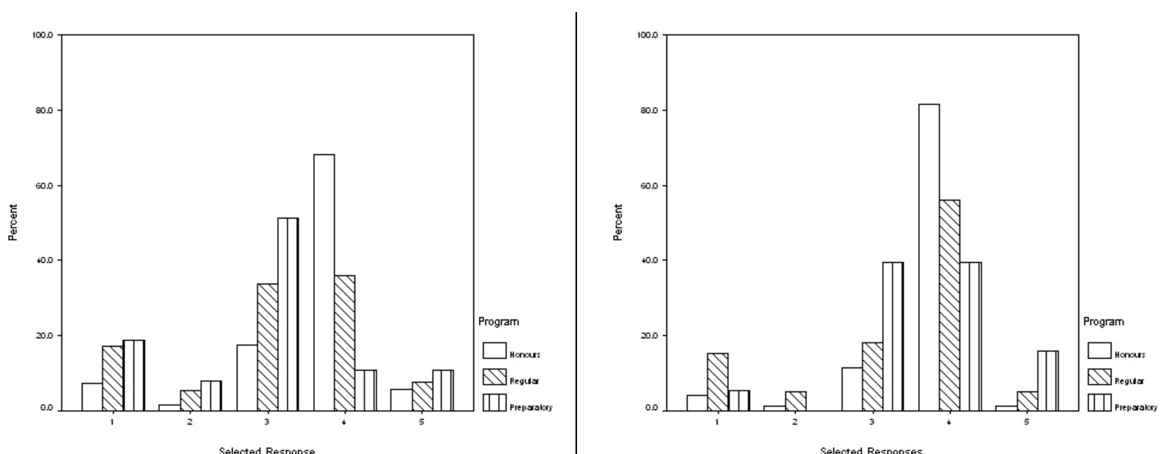
The multivariate repeated measures test for question 20 (discriminating velocity from acceleration) indicates that there is a significant interaction of gender and program on the gains in understanding on this question (F=17.26, df=242, 2, p=.001). Although the overall percentage of students who answered this question correctly increased from 41% to 61%, not all students improved. In the honours program, only male students improved with the percent of male students answering the question correctly increasing from 65% to 84%. In the regular program, male and female students improved equally with the percent of students answering question 20 correctly increasing from 36% to 54%. In the preparatory program, only female students improved, with the percent of female students answering the question correctly increasing from 0% to 48%. The most popular wrong answer remained 3, indicating that students were not discriminating acceleration from velocity.

Figures 8 shows that the pattern of responses students made answering question 20 also did not change between the pretest and posttest.



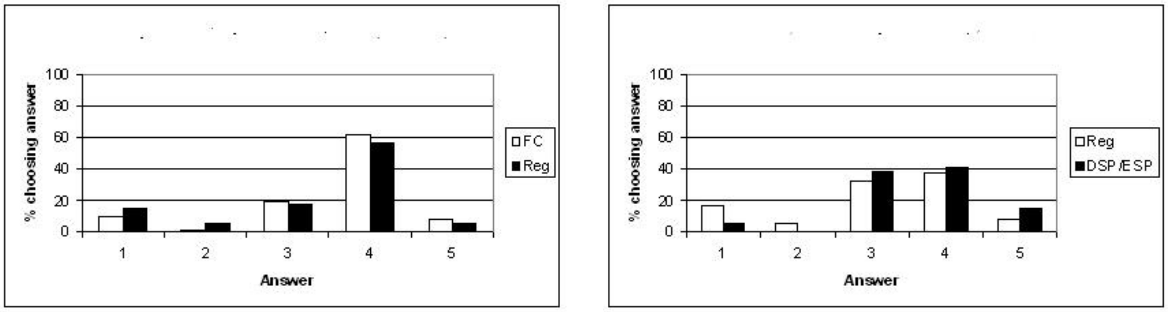

(a) (b)

Figure 7. Comparison of responses on the posttest of students in the regular program (■) to responses on the pretest of students in the honours program (□) for question 19 (a) and of responses on the posttest of students in preparatory program (■) to the responses on the pretest of students in the regular program (□) for question 19(b).




(a) pretest (b) posttest

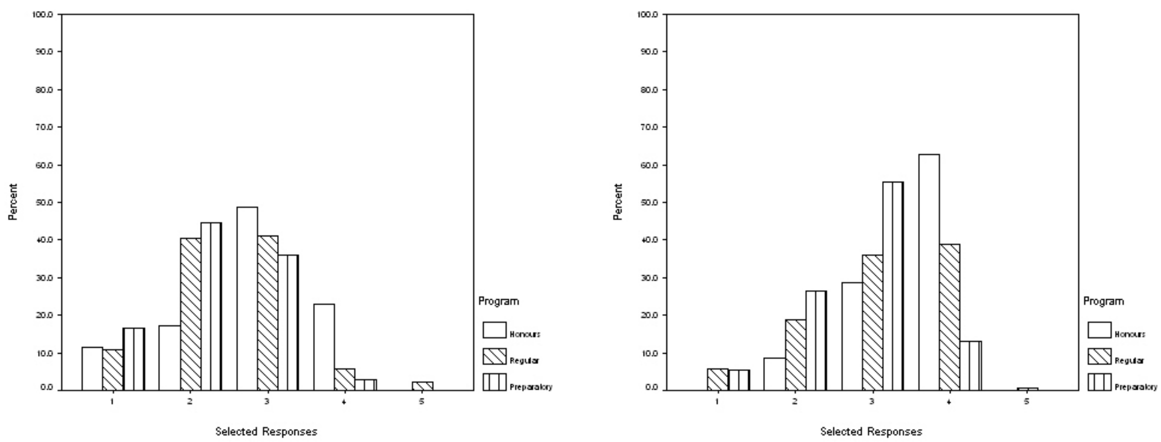
Figure 8. Student responses on question 20 on pretest (a) and posttest (b). Correct answer is 4.




(a) (b)

Figure 9. Comparison of responses on the posttest of students in the regular program (■) to responses on the pretest of students in the honours program (□) for question 20 (a) and of responses on the posttest of students in preparatory program (■) to the responses on the pretest of students in the regular program (□) for question 20(b).

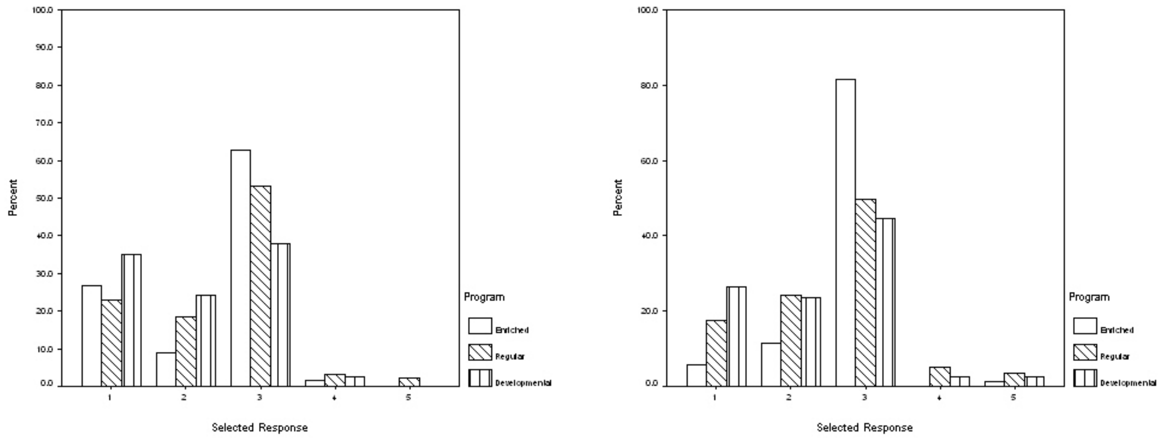
The abridged FCI has two questions that test students' understanding of forces. Question 13 (see Appendix 1) is a measure of students' understanding of vertical force (i.e., gravity). Question 27 (see Appendix 1) is a measure of students' understanding of horizontal force (i.e., friction). The multivariate repeated measures test for question 13 indicates that there is a significant influence of program on the gains in understanding on this question (F=8.58, df=241,2, p=.000). Only students in the Enriched and Regular Programs improved their response to this question (40% and 33%), respectively. Figure 10 shows that the most frequently chosen wrong answer for question 27 assumes a non-existent upward force. Even students in the enriched program kept this misconception after instruction with almost 30% of the students in this program selecting this option (c) on the posttest.




(a) (b)

Figure 10. Student responses on question 13 on pretest (a) and posttest (b). correct answer is 4.

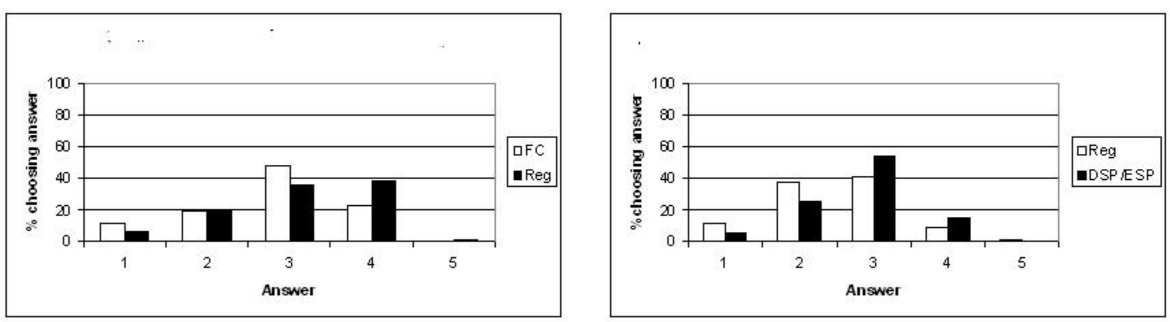
Similarly, the multivariate repeated measures test for question 27 indicates that there is a significant influence of program on the gains in understanding on this question (F=3.38, df=241,2, p=.04) Only, students in the honours program improved their response on the question on horizontal forces (from 60% to 81%). Figure 11 shows that in general only the students in the enriched program have improved their performance on question 27(which tests students understanding of friction). The most frequently chosen wrong answers (a and b) indicate that students still believe in an additional force, namely impetus and misidentify active and passive agents of force. Thus, the responses to both questions indicate that most students in the regular and preparatory programs have difficulty with questions dealing with vertical and horizontal forces.




(a) (b)

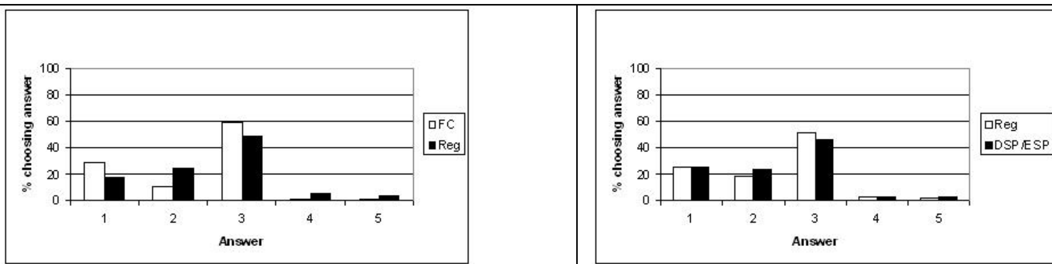
Figure 11. Student responses on question 27 on pretest (a) and posttest (b).

Figures 12 and 13 again show that instruction shift the pattern of responses on questions testing students understanding of force to the pattern of the more able students before instruction.




(a) (b)

Figure 12. Comparison of responses on the posttest of students in the regular program (■) to responses on the pretest of students in the honours program (□) for question 139 (a) and of responses on the posttest of students in preparatory program (■) to the responses on the pretest of students in the regular program (□) for question 13(b).




| (a) | (b) |
|---|---|

Figure 13. Comparison of responses on the posttest of students in the regular program (■) to responses on the pretest of students in the honours program (□) for question 27 (a) and of responses on the posttest of students in preparatory program (■) to the responses on the pretest of students in the regular program (□) for question 27(b).

Numerous researchers have shown that students are often confused with the precise meaning of the concepts position, velocity, and acceleration. They, not only misinterpret graphs that demonstrate relationships between these variables, they also use the wrong equations or put the wrong values in the equation. Thus, a superficial understanding of this term has catastrophic consequences of their subsequent learning of Newton's Laws.

One of the ways in which students in the honours program differed from the students in the other Programs is that they come into the College mechanics course with a strong understanding of both kinematics and forces. This understanding is a prerequisite to beginning to understand Newton's Laws. Students that are still in Stage 1, will have a greater difficulty in Thus,in both regular and preparatory classes, teachers spend close to the first half of the course reviewing these concepts. However, since students have covered these concepts in their high school courses, they may think they know this material and not attend to this material.

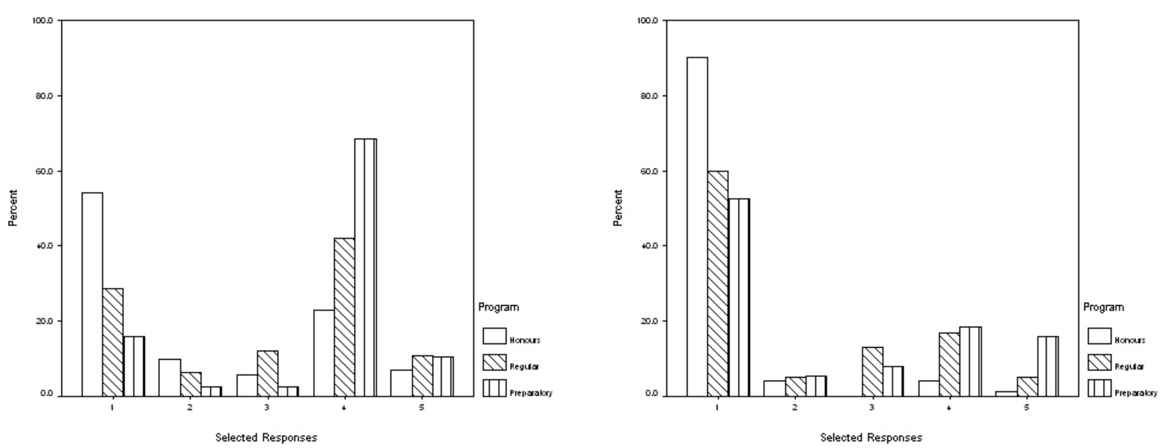
## First Law Questions

We analyzed four questions from the abridged FCI (10, 11, 25 and 26) that probe students' understanding of Newton's First Law: ***Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it***. Newton's First Law predicts the behaviour of an object when either there is no force (question 10) acting on the object or the forces cancel each other out (questions 11, 25 and 26). Given that many students appear to hold a pre-Newtonian conceptual understanding of force and motion, one would expect this to affect their answers on these tthree questions.

The multivariate repeated measures test for question 10 (Newton's First Law with no forces) indicates that there is a significant (F=65.56, df=241,2,p=.000) improvement on this question with instruction for all students. The percentage of the students who answered this question correctly increased from 34.8% to 67.3%.

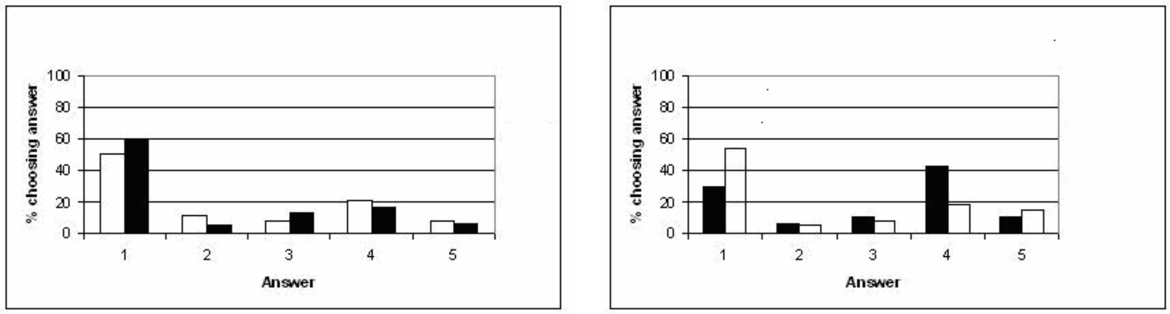
Figure 14 indicates that instruction helped most students drop the idea of impetus when no force was present. Those students who still answered incorrectly believed that impetus influenced motion. However, they may have included friction in spite of the fact that the question stipulates a frictionless surface.

Figure 15 shows that instruction helped students in the regular program respond to question 10 similarly to students in the honours program before instruction. However, instruction appeared to help the preparatory students more than "catch up" with the regular students in that more students than expected in switched their responses from 4 to 1.




(a) (b)

Figure 14. Student responses on question 10 on pretest (a) and posttest (b). Correct answer is 1.



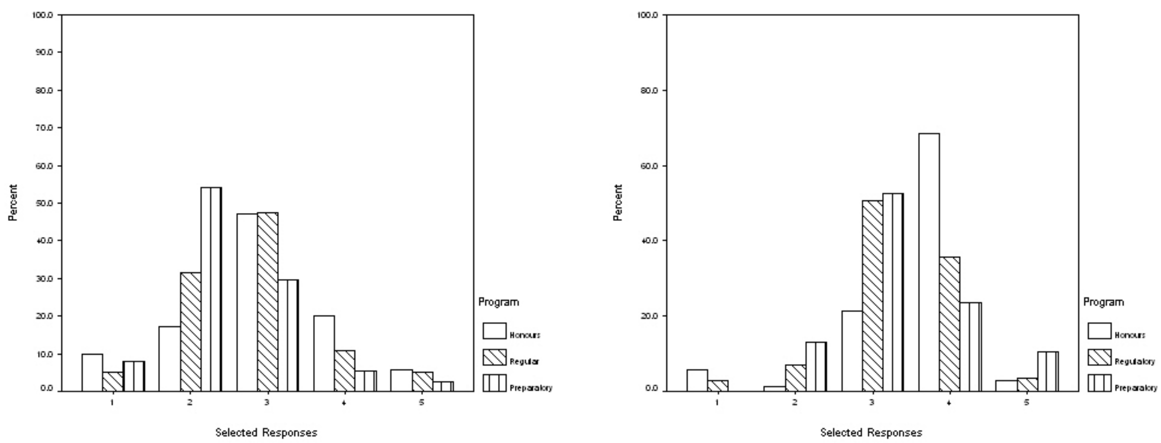

(a) (b)

Figure 15. Comparison of responses on the posttest of students in the regular program (■) to responses on the pretest of students in the honours program (□) for question 10 (a) and of responses on the  posttest of students in preparatory program (■) to the responses on the pretest of students in the regular program (□) for question 10(b).

The multivariate repeated measures test for questions 11, 25, and 26 ((F=6.51, df=241,2,.002), (F=5.45, df=241,2, p=.005) and (F=7.378, df=241,2, p=.001), respectively) indicate that there is a significant influence of program on the gains on these three questions testing students' understanding of First Law with canceling forces.

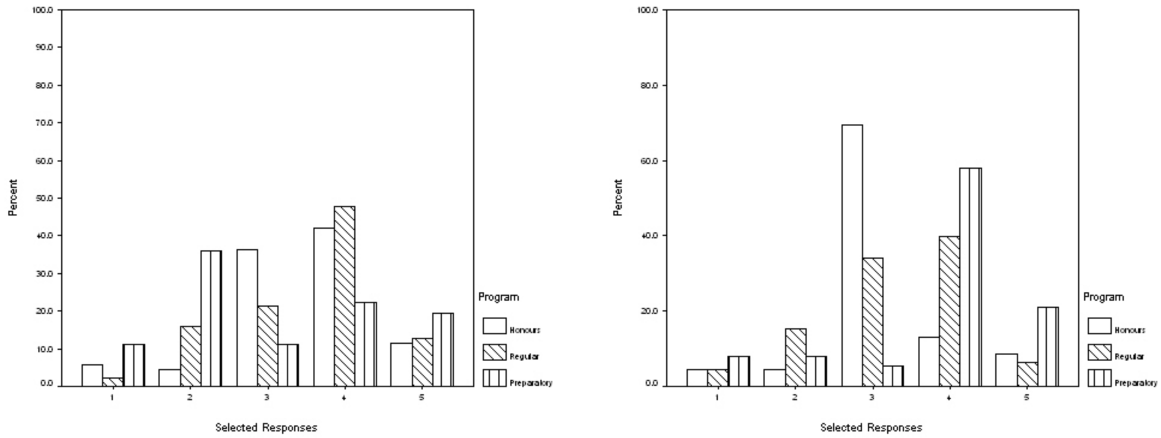
Figures 16, 17, and 18 show the gains in understanding First Law were quite similar for questions 11, 25, and 26. In all cases, only students in the honours and regular programs significantly increased their understanding. The percentage of students who answered question 11 correctly increased from 20% to 69% for honours students and from 11% to 36% for regular students. The most common wrong answer was 3, indicating that students believed that a force in the direction of motion is required to maintain a constant velocity. The percentage of students who answered question 25 correctly increased from 36%  to 66% for honours students and from 21% to 33% for regular students. The most popular wrong answer was 4, indicating that students believe that it takes a net force greater than 0 to push an object at constant speed. The percentage of students who answered question 26 correctly increased from 22% to 54% for honours students and from 11% to 22% for regular students. The most common wrong answer was 2, indicating that students believe that doubling the force produces a temporary acceleration that wears off. That is, the pattern of responses to all three questions indicates that students have persistent misconceptions about active force.

Figures 19a, 20a, and 21a compare the responses of the students in the regular program **after** taking the introductory mechanics course with those of the students in the honours program **before** taking the course. It again indicates that instruction appears to bring the pattern of responses of the students in the regular program to that of the students in the honours program before instruction. However, Figures 19b, 20b, and 21b comparing the responses of students in the preparatory program **after** taking the introductory mechanics course with those of the students in the regular program **before** taking the course, indicate that instruction has not helped the students in the preparatory program lose their misconceptions about active forces.



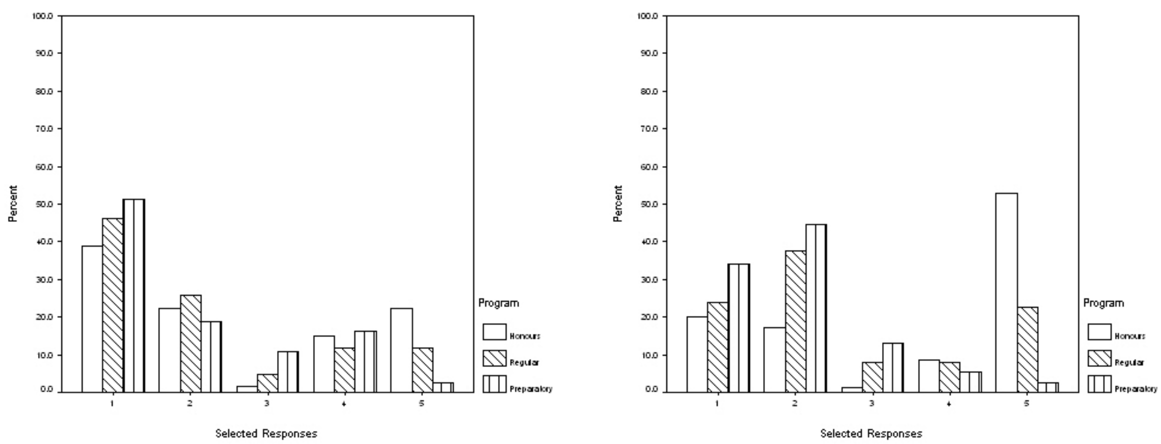

(a) (b)

**Figure 16.** Student responses on question 11 on pretest (a) and posttest (b). Correct answer is 4.



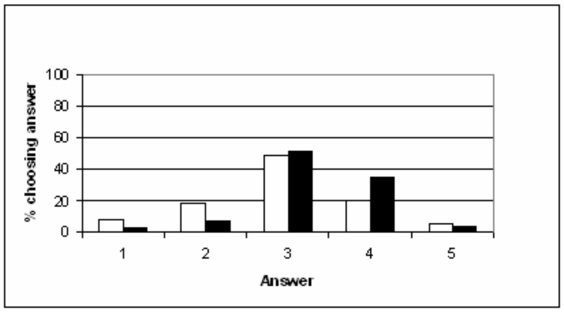

(a) (b)

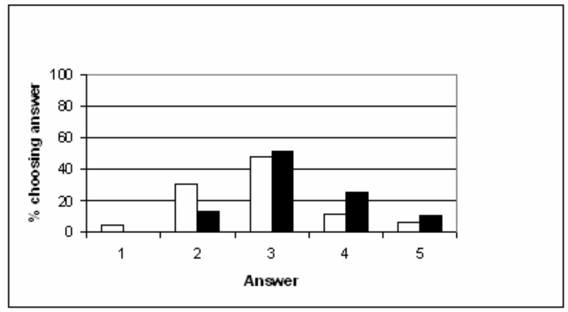
**Figure 17.** Student responses on question 25 on pretest (a) and posttest (b). Correct answer is 3.




(a) (b)

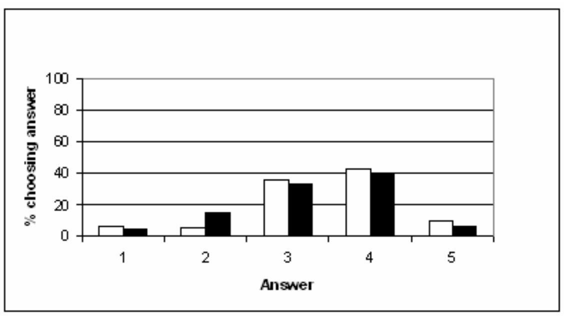
**Figure 18.** Student responses on question 26 on pretest (a) and posttest (b). Correct answer is 5.

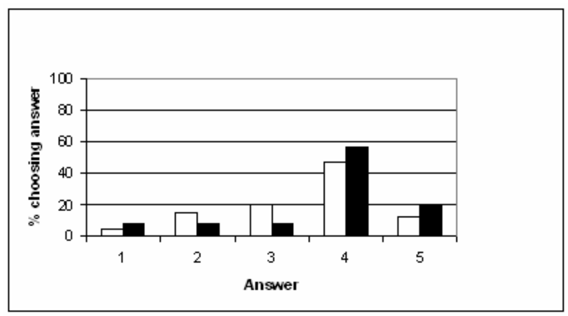



(a) (b)

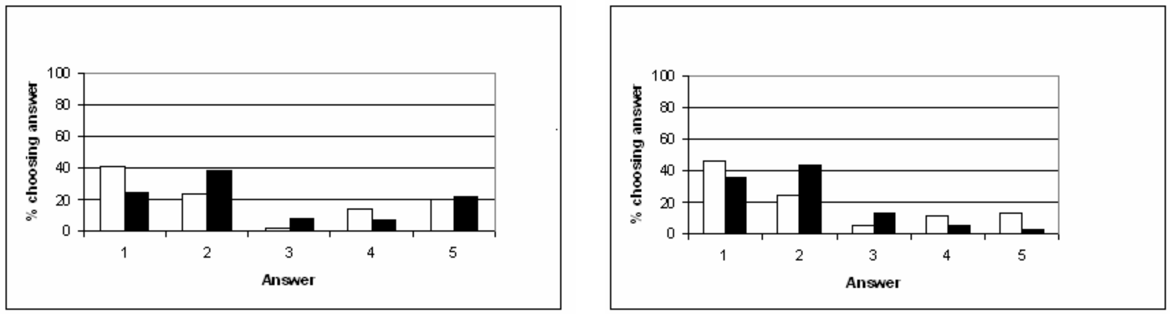
**Figure 19.** Comparison of responses on the posttest of students in the regular program (■) to responses on the pretest of students in the honours program (□) for question 11 (a) and of responses on the posttest of students in preparatory program (■) to the responses on the pretest of students in the regular program (□) (b). Correct answer is 4.




(a) (b)

**Figure 20.** Comparison of responses on posttest of students in the regular program(■) to responses on the pretest of students in the honours program (□) for question25(a) and of responses on posttest of students in the preparatory program (■)to responses on the pretest of students in the regular program (□) (b).Correct answer is 3.




(a) (b)

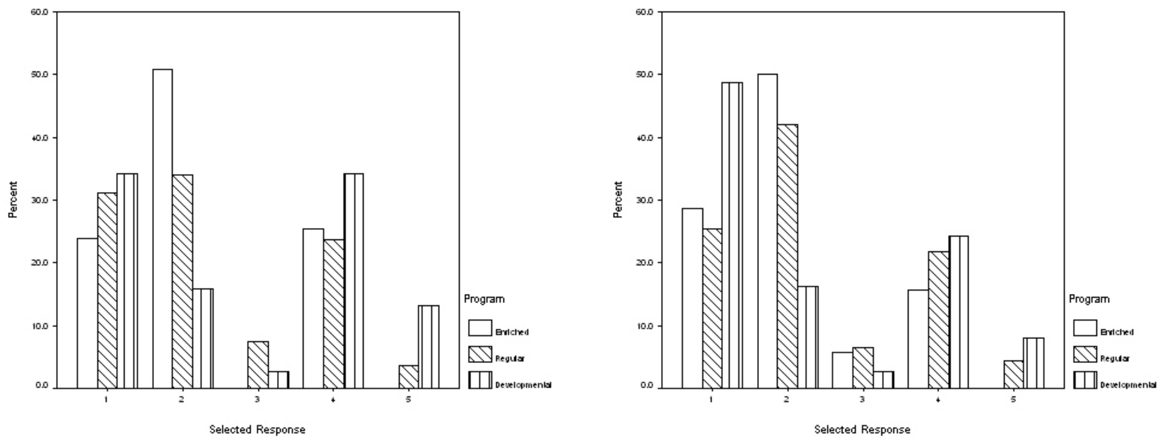
**Figure 21.** Comparison of responses on the posttest of students in the regular program (■) to responses on the pretest of students in the honours program (□) for question 26 (a) and of responses on the posttest of students in preparatory program (■) to the responses on the pretest of students in the regular program (□) for question 26(b). Correct answer is 5.

In general, only honours and regular students appeared to gain an understanding of First Law. The results were quite consistent over the four questions in the FCI. While most students appeared to answer the question on First Law with no force, only about 60% of the honours students and 30% of the regular students were able to answer the three questions on First Law with canceling forces.

## Second Law Questions

We analyzed one question from the abridged FCI (question 22) that tested students' understanding of Newton's Second Law: ***The acceleration of an object is directly proportional to the net force acting upon it and inversely proportional to the mass of the object***. Newton's Second Law predicts the behaviour of an object when an unbalanced force is acting on the object.. Given that many students appear to hold a pre-Newtonian conceptual understanding of force and motion, one would expect this to affect their answers on questions probing the Second Law.

The multivariate repeated measures test indicates that there is no improvement on the posttest for this question. Figure 22 shows that the distribution of answers before and after instruction was the same. That is, instruction appeared to have no effect on students' conceptual understanding of the Second Law




(a) (b)

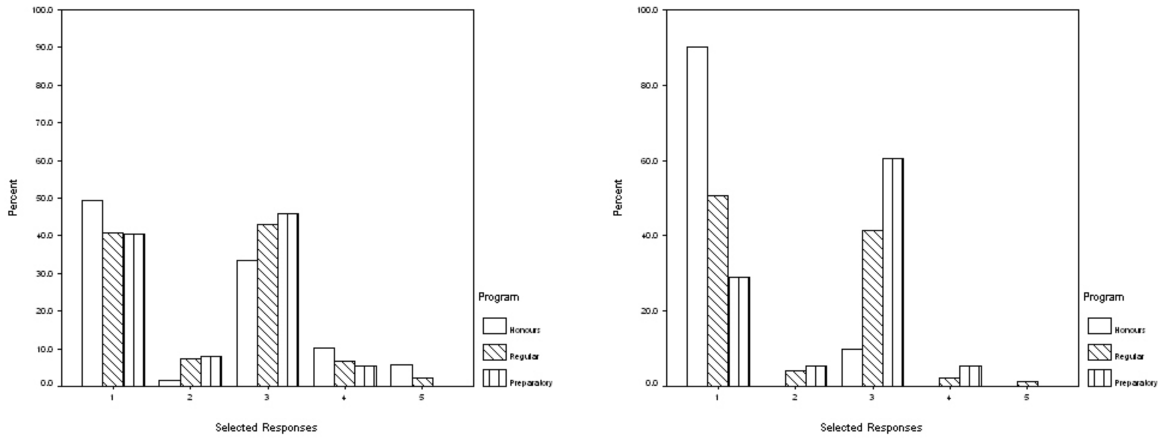
Figure 22. Student responses on question 22 on pretest (a) and posttest (b). Correct answer is 2.

It also shows that students in all programs chose the wrong answers 1 and 4 quite frequently (about 50%). These incorrect responses indicate that students believe that when a rocket is fired, and the engine is turned on producing a thrust, the speed will either remain constant or become constant after an initial acceleration.

## Third Law Questions

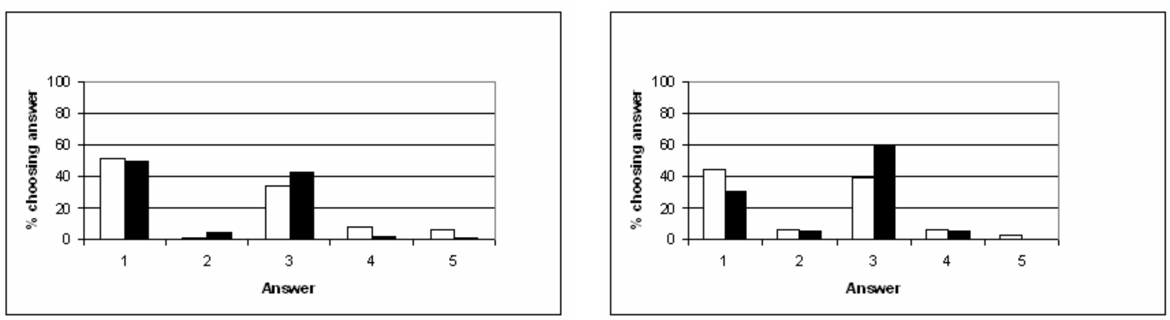
We analyzed one question from the abridged FCI (question 16) that probes students' understanding of Newton's Third Law: ***For every action, there is an equal and opposite reaction.*** Newton's Third Law predicts the behaviour of interacting objects whether the interactions are contact interactions or action-at-a-distance interactions.

The multivariate repeated measures test for questions 16 (F=8.69, df=241,2, p=.000) indicates that there is a significant influence of program on the gains in understanding on Third Law. Only students in the honours program improved their understanding of Third Law. Figure 23 shows the distribution of selected responses. It indicates that the most popular wrong answer for all students was c, implying that the car, which is pushing the truck exerts a large force on the truck than the stalled truck does on the car.




(a) (b)

Figure 23. Student responses on question 16 on pretest (a) and posttest (b). Correct answer is 1.




(a) (b)

Figure 24. Comparison of responses on the posttest of students in the regular program (■) to responses on the pretest of students in the honours program (□) for question 16 (a) and of responses on the posttest of students in preparatory program (■) to the responses on the pretest of students in the regular program (□) (b). Correct answer is 1.

# GENERAL DISCUSSION AND CONCLUSIONS

*Students with FCI scores below 60% do not have sufficient mastery of Newtonian concepts to use them reliably in problem solving or scientific reasoning. Consequently, they systematically misunderstand most of what they hear and read about physics; they have no alternative to rote methods in studying for examinations, and they suffer frustration and humiliation from not understanding what they are doing wrong. At the university level, this applies to about half the students completing physics under traditional instruction*[2].

The above quote summarizes the implications of our results with the FCI. The FCI can be used to determine at whether students have an incoherent understanding of the physics concepts, i.e., forces, velocity, position, acceleration (Stage I); have a naïve or fragile model of the laws of motion (Stage 2); or have the correct model of the laws of motion and can apply them consistently (Stage 3). In our investigation of college students' conceptual understanding of forces and motion, more than 60% were at Stage 1 at the end of an introductory course in mechanics. More female students than male students remained at Stage 1 after instruction. Their performance both at the beginning of the course and at the end of the course was associated with their general academic ability (as determined by their Program of Entry), their gender, and their reading comprehension.

Given, that so many students have difficulty with the basic concepts of forces and motion, it is not surprising that except for the honours students (who do not have these difficulties) few develop a better understanding of Newton's three laws. The literature emphasizes that classes which promote the cognitive active engagement of students with physics, improve the most. This suggests that introductory physics classes should include activities which promote students "deep" conversions about the essential meaning of the physics basic concepts

[2] Quoted from speech by David Hestenes at the AAPT conference in 2000 for physics department chairs available at http://modeling.asu.edu/rup_workshop/design.html

# APPENDIX 1

DOCUMENT LITERACY

Please write your answers in the space provided.

Name: Student ID#

**Question 1: Periodic Table (Document 1)**

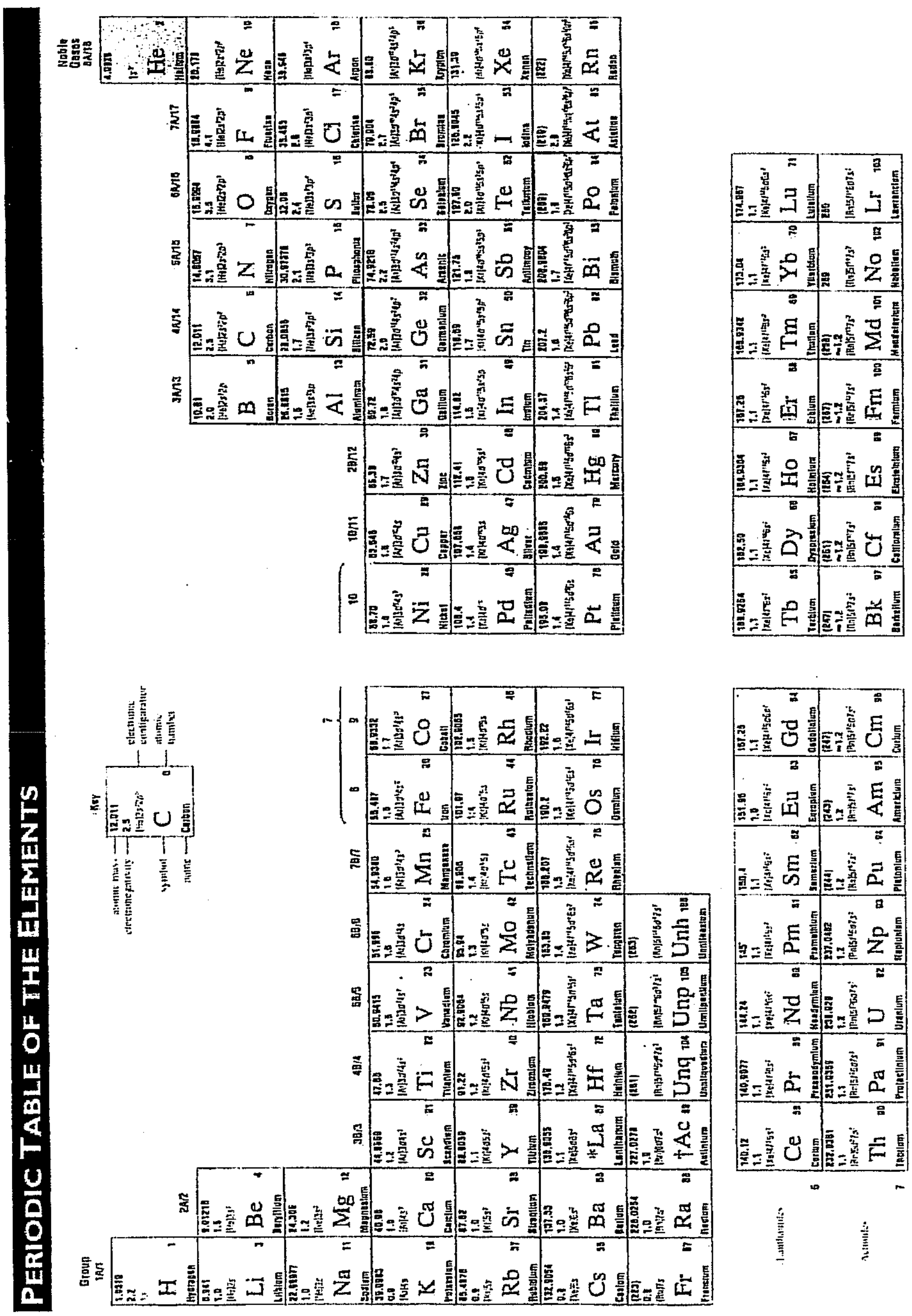
Using Document 1 (The Periodic Table) answer the following questions:

a) How many elements have no listed electronegativity? ____________

b) Of these, which element has the highest atomic mass? ____________

c) What is the atomic mass of carbon (symbolized by the letter *C*)? ____________

## Document 1
## PERIODIC TABLE



**Question 2: Straight Chain Alkanes (Document 2) and Document 1 (Periodic Table)**

Using Document 2 (Straight Chain Alkanes) and Document 1 (The Periodic Table) answer the following questions:

a) What is the molecular formula for hexane? ______________________________

b) The molecular weight of a compound is the sum of the atomic mass of all the atoms (elements) in the compound. What is the molecular weight of methane to the nearest whole number? ______________

# Document 2

## Straight Chain Alkanes

| # Carbon | Name | Molecular Formula | Structural Formula |
|---|---|---|---|
| 1 | Methane | $CH_4$ | $CH_4$ |
| 2 | Ethane | $C_2H_6$ | $CH_3CH_3$ |
| 3 | Propane | $C_3H_8$ | $CH_3CH_2CH_3$ |
| 4 | Butane | $C_4H_{10}$ | $CH_3CH_2CH_2CH_3$ |
| 5 | Pentane | $C_5H_{12}$ | $CH_3CH_2CH_2CH_2CH_3$ |
| 6 | Hexane | | $CH_3(CH_2)_4CH_3$ |
| 7 | Heptane | $C_7H_{16}$ | $CH_3(CH_2)_5CH_3$ |
| 8 | Octane | $C_8H_{18}$ | $CH_3(CH_2)_6CH_3$ |
| 9 | Nonane | $C_9H_{20}$ | $CH_3(CH_2)_7CH_3$ |
| 10 | Decane | $C_{10}H_{22}$ | $CH_3(CH_2)_8CH_3$ |

**Question 3: Organic Carbon Cycle (Document 3)**

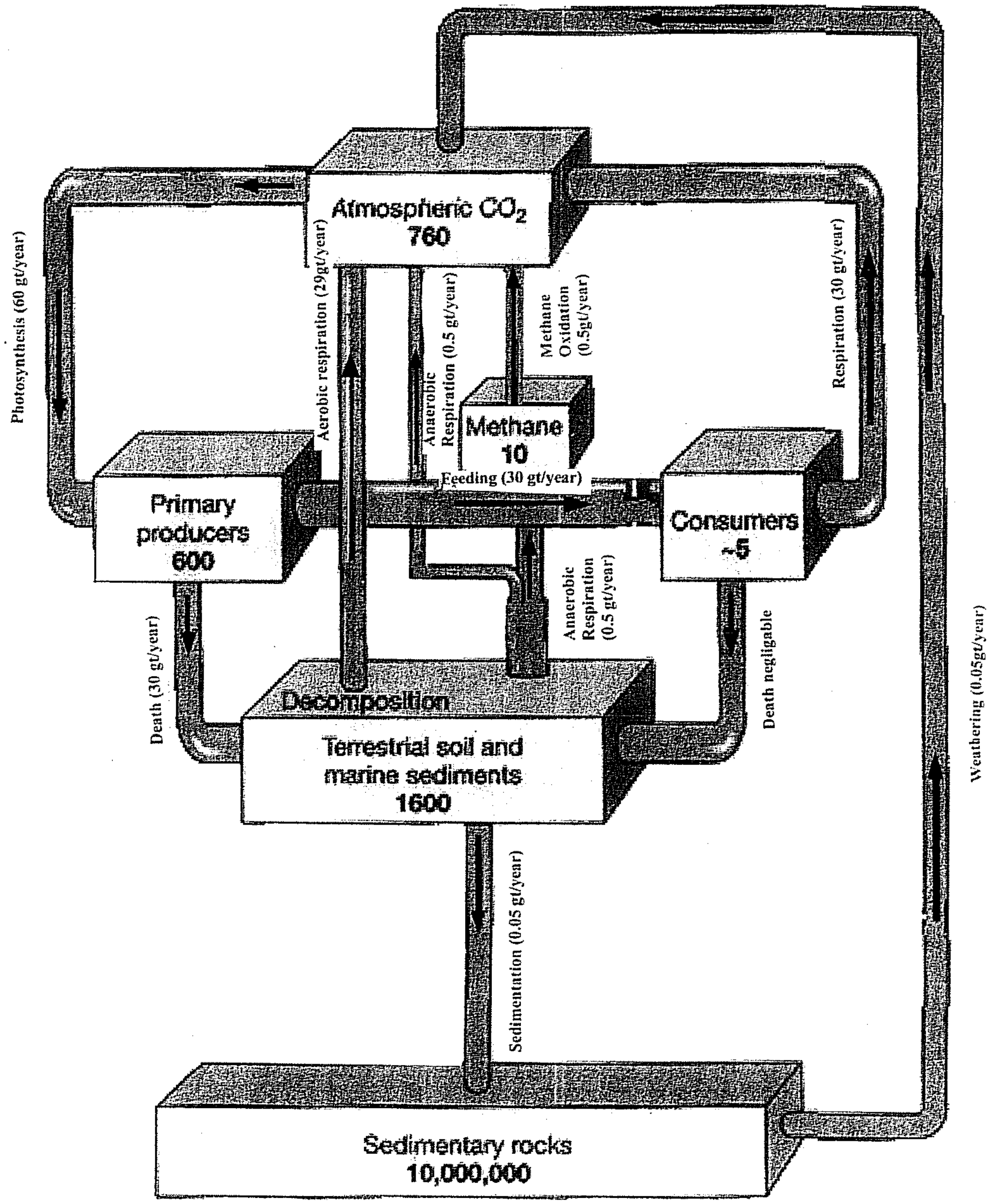
Using Document 3 (Organic Carbon Cycle) answer the following questions:

a) How many gigatons of carbon are released as carbon dioxide into the atmosphere every year by the weathering of sedimentary rocks?____________________

b) The primary producers are plants and the consumers are animals. Given the flows (input and output) of carbon to and from plants and animals, what is the net accumulation in gigatons of carbon in plants?_______

c) List the input sources and the fluxes of carbon into the atmosphere in gigatons per year.

## Document 3
## ORGANIC CARBON CYCLE



**Question 4: Halley's Comet (Document 4)**

Using Document 4 (Halley's Comet) answer the following questions:

a) How long does it take Halley's comet to complete an orbit? ______________________

b) Approximately what year will Halley's comet next cross Earth's orbit? ______________

c) Halley's comet is next to which planet's orbit when it crosses the orbital plane of Earth? __________________

# Document 4
# HALLEY'S COMET

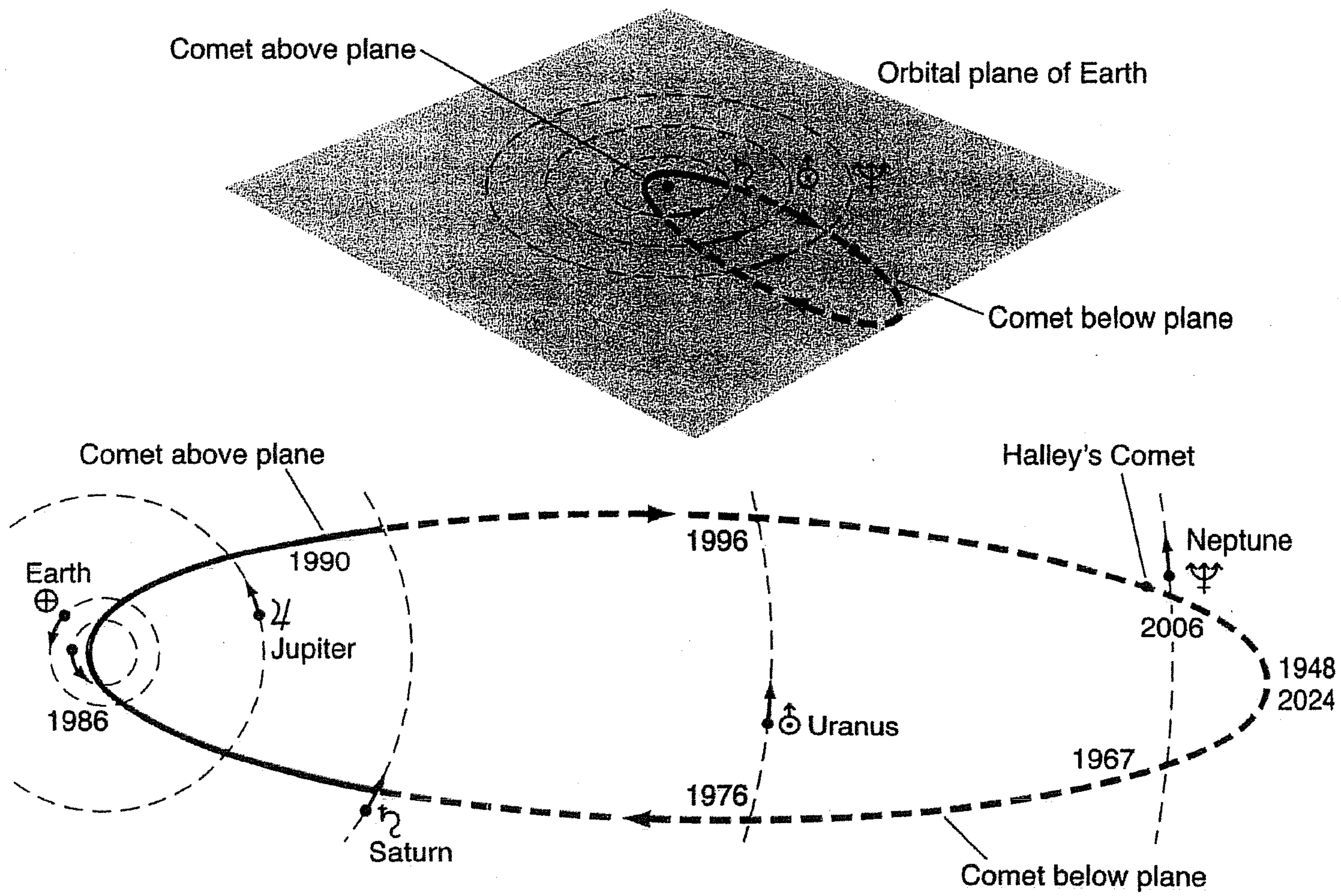



**Figure 11.8** Unlike the planets, comets have orbits that are inclined at all possible angles. For example, Halley's comet, depicted here, orbits the sun in the opposite direction to that of the planets; that is, its orbit is inclined by more than 90° to the planets' orbits.

**Question 5: Atmosphere of Venus (Document 5)**

Using Document 5 (Atmosphere of Venus) answer the following questions:

a) What is the major gas in the mesosphere of Venus?______________________________

b) What is the height, temperature, pressure, and atmospheric region at point "**X**"? Please use appropriate units.

______________________________

______________________________

______________________________

______________________________

c) At what height is the temperature of the atmosphere the lowest? What is that temperature? Please give the appropriate units.

______________________________

______________________________

# Document 5
# ATMOSPHERE of VENUS

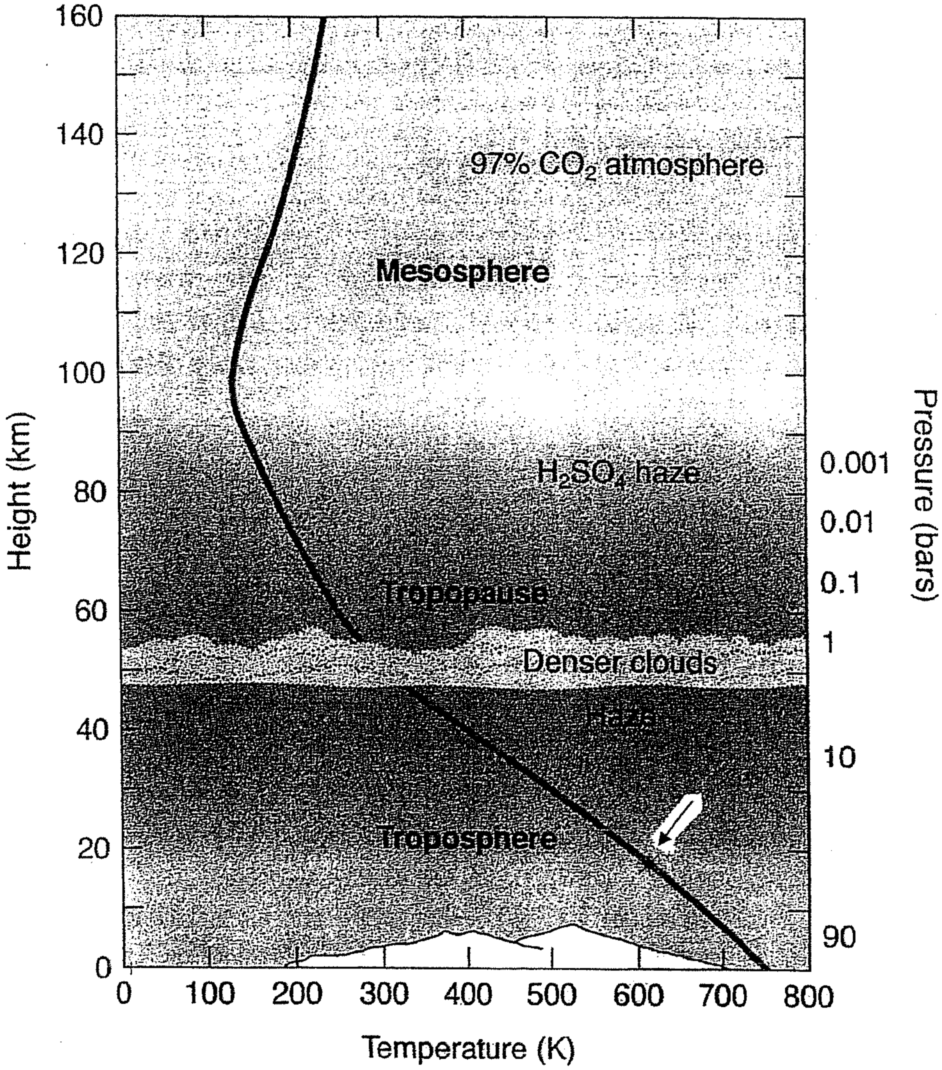



**Figure 12.6** At an altitude of 53 kilometers above the surface of Venus, the temperature falls by 440° C to a warmish 37° C, and the pressure decreases to less than 1 percent of its surface value.

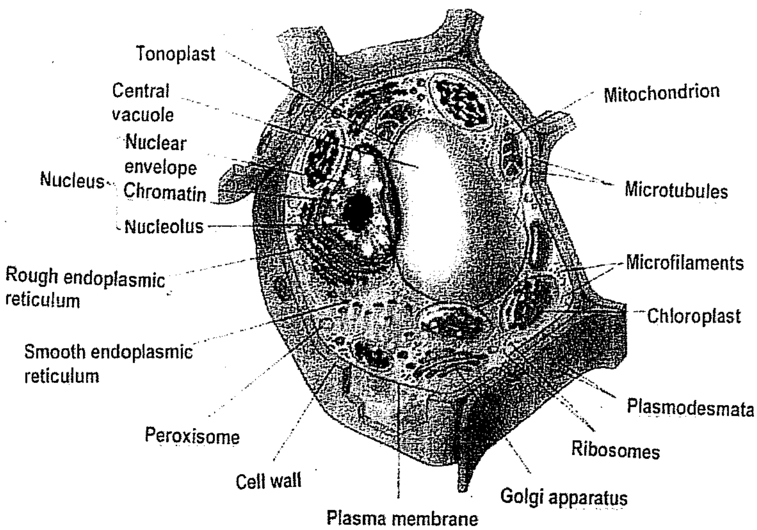
**Question 6: Plant and Animal Cells (Document 6)**

Using Document 6 (Plant and Animal Cells) answer the following questions:

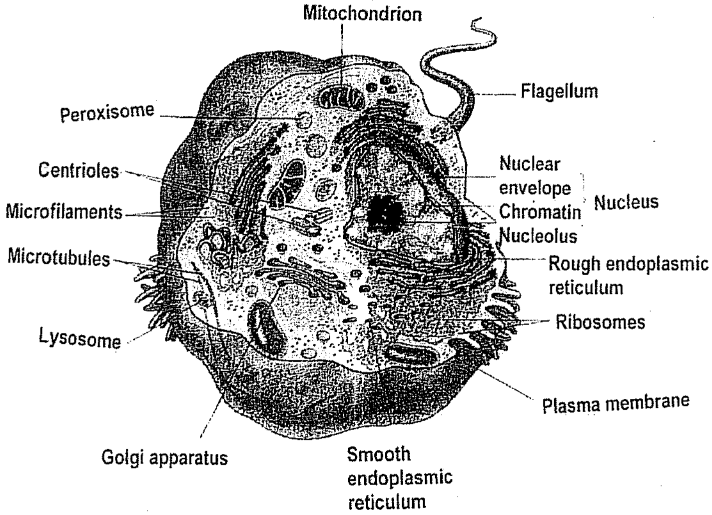
a) Do both cells have similar nuclei? Explain.____________________________________________

b) Create a table indicating the cell structures which are (a) common to both cell types and (b) unique to each.

## Document 6
## Comparison of Plant (a) and Animal Cells (b)




(a) Plant Cell




(b) Animal Cell

**Question 7: Properties of Fatty Acids (Document 7)**

Using Document 7 (Properties of Fatty Acids) answer the following questions:

a) Compare the following four fatty acids: Dodecanoic acid, $C_{18}H_{36}O_2$, Palmitic acid, and $C_6H_{12}O_2$. Of the four, give the common name of the fatty acid with the highest melting point?________________

b) Describe the relationship between molecular size and aqueous solubility in fatty acids?________________

c) How many monounsaturated fatty acids have less than 20 carbons?________________

# Document 7
# PROPERTIES of FATTY ACIDS

This table gives the systematic names and selected properties of some of the more important fatty acids of five or more carbon atoms. Compounds are listed first by degree of saturation and, secondly, by number of carbon atoms. The following data are included:

$M_r$: Molecular weight
$S$: Aqueous solubility at 20°C in units of grams of solute per 100 grams of water
$t_m$: Melting point in °C

## References


1. Dawson, R. M. C., Elliott, D. C., Elliott, W. H., and Jones, K. M., *Data for Biochemical Research*, 3rd ed., Clarendon Press, Oxford, 1986.
2. Fasman, G. D., Ed., *Practical Handbook of Biochemistry and Molecular Biology*, CRC Press, Boca Raton, FL, 1989.


| Common name | Systematic name | Mol. form. | $M_r$ | $t_m$/°C | $S$ |
|---|---|---|---|---|---|
| ***Saturated*** | | | | | |
| Valeric acid | Pentanoic acid | $C_5H_{10}O_2$ | 102.13 | −33.6 | 2.5 |
| Isovaleric acid | 3-Methylbutanoic acid | $C_5H_{10}O_2$ | 102.13 | −29.3 | 4.3 |
| Caproic acid | Hexanoic acid | $C_6H_{12}O_2$ | 116.16 | −3 | 0.967 |
| Enanthic acid | Heptanoic acid | $C_7H_{14}O_2$ | 130.19 | −7.17 | 0.24 |
| Caprylic acid | Octanoic acid | $C_8H_{16}O_2$ | 144.21 | 16.5 | 0.080 |
| Pelargonic acid | Nonanoic acid | $C_9H_{18}O_2$ | 158.24 | 12.4 | 0.0284 |
| Capric acid | Decanoic acid | $C_{10}H_{20}O_2$ | 172.27 | 31.4 | 0.015 |
| Lauric acid | Dodecanoic acid | $C_{12}H_{24}O_2$ | 200.32 | 43.8 | 0.0055 |
| Tridecylic acid | Tridecanoic acid | $C_{13}H_{26}O_2$ | 214.35 | 41.5 | 0.0033 |
| Myristic acid | Tetradecanoic acid | $C_{14}H_{28}O_2$ | 228.38 | 54.2 | 0.0020 |
| Pentadecylic acid | Pentadecanoic acid | $C_{15}H_{30}O_2$ | 242.40 | 52.3 | 0.0012 |
| Palmitic acid | Hexadecanoic acid | $C_{16}H_{32}O_2$ | 256.43 | 62.5 | 0.00072 |
| Margaric acid | Heptadecanoic acid | $C_{17}H_{34}O_2$ | 270.46 | 61.3 | 0.00042 |
| Stearic acid | Octadecanoic acid | $C_{18}H_{36}O_2$ | 284.48 | 69.3 | 0.00029 |
| Arachidic acid | Eicosanoic acid | $C_{20}H_{40}O_2$ | 312.54 | 76.5 | |
| Phytanic acid | 3,7,11,15-Tetramethylhexadecanoic acid | $C_{20}H_{40}O_2$ | 312.54 | -65 | |
| Behenic acid | Docosanoic acid | $C_{22}H_{44}O_2$ | 340.59 | 81.5 | |
| Lignoceric acid | Tetracosanoic acid | $C_{24}H_{48}O_2$ | 368.64 | 87.5 | |
| Cerotic acid | Hexacosanoic acid | $C_{26}H_{52}O_2$ | 396.70 | 88.5 | |
| Montanic acid | Octacosanoic acid | $C_{28}H_{56}O_2$ | 424.75 | 90.9 | |
| ***Monounsaturated*** | | | | | |
| Caproleic acid | 9-Decenoic acid | $C_{10}H_{18}O_2$ | 170.25 | 26.5 | |
| Palmitoleic acid | *cis*-9-Hexadecenoic acid | $C_{16}H_{30}O_2$ | 254.41 | 0.5 | |
| Oleic acid | *cis*-9-Octadecenoic acid | $C_{18}H_{34}O_2$ | 282.47 | 13.4 | |
| Elaidic acid | *trans*-9-Octadecenoic acid | $C_{18}H_{34}O_2$ | 282.47 | 45 | |
| Vaccenic acid | *trans*-11-Octadecenoic acid | $C_{18}H_{34}O_2$ | 282.47 | 44 | |
| Erucic acid | *cis*-13-Docosenoic acid | $C_{22}H_{42}O_2$ | 338.57 | 34.7 | |
| Brassidic acid | *trans*-13-Docosenoic acid | $C_{22}H_{42}O_2$ | 338.57 | 61.9 | |
| Nervonic acid | *cis*-15-Tetracosenoic acid | $C_{24}H_{46}O_2$ | 366.63 | 43 | |
| ***Diunsaturated*** | | | | | |
| Linoleic acid | *cis,cis*-9,12-Octadecadienoic acid | $C_{18}H_{32}O_2$ | 280.45 | −7 | |
| ***Triunsaturated*** | | | | | |
| *cis*-Eleostearic acid | *trans,cis,trans*-9,11,13-Octadecatrienoic acid | $C_{18}H_{30}O_2$ | 278.44 | 49 | |
| *trans*-Eleostearic acid | *trans,trans,trans*-9,11,13-Octadecatrienoic acid | $C_{18}H_{30}O_2$ | 278.44 | 71.5 | |
| Linolenic acid | *cis,cis,cis*-9,12,15-Octadecatrienoic acid | $C_{18}H_{30}O_2$ | 278.44 | −11 | |
| ***Tetraunsaturated*** | | | | | |
| Arachidonic acid | 5,8,11,14-Eicosatetraenoic acid, (all-*trans*) | $C_{20}H_{32}O_2$ | 304.47 | −49.5 | |

# Force Concept Inventory

*Please:*

*Do **not** write anything on this questionnaire.*

*Mark your answers on the ParSCORE computer sheet.*

*Make **only one** mark per item.*

*Do **not** skip any question.*

*Avoid guessing. Your answers should reflect what **you** personally think.*

*On the ParSCORE computer sheet:*

*Use a **No. 2 pencil** only, and follow marking instructions.*

*Fill in your ID number. This is the number given to you by your school or your teacher.*

*Mark "A" under "Test Form".*

*Fill in the "Exam No." given by your teacher.*

*Plan to finish this questionnaire in 30 minutes.*

*Thank you for your cooperation.*

1. Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single 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 as for the lighter one.
   (B) about half as long for the lighter ball as for the heavier one.
   (C) about the same 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.

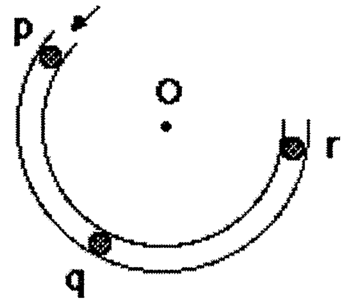
2. The two metal balls of the previous problem roll off a horizontal table with the same speed. In this situation:
   (A) both balls hit the floor at approximately the same horizontal distance from the base of the table.
   (B) the heavier ball hits the floor at about half the horizontal distance from the base of the table than does the lighter ball.
   (C) the lighter ball hits the floor at about half the horizontal distance from the base of the table than does the heavier ball.
   (D) the heavier ball hits the floor considerably closer to the base of the table than the lighter ball, but not necessarily at half the horizontal distance.
   (E) the lighter ball hits the floor considerably closer to the base of the table than the heavier ball, but not necessarily at half the horizontal distance.

3. A stone dropped from the roof of a single story building to the surface of the earth:
   (A) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
   (B) speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the earth.
   (C) speeds up because of an almost constant force of gravity acting upon it.
   (D) falls because of the natural tendency of all objects to rest on the surface of the earth.
   (E) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

4. A large truck collides head-on with 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 does not 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.

**USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (5 and 6).**

The accompanying figure shows a frictionless channel in the shape of a segment of a circle with center at "O". The channel has been anchored to a frictionless horizontal table top. You are looking down at the table. Forces exerted by the air are negligible. A ball is shot at high speed into the channel at "p" and exits at "r."

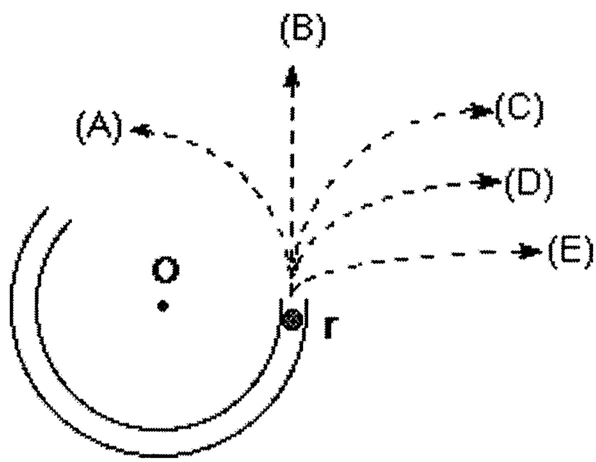



5. Consider the following distinct forces:
   1. A downward force of gravity.
   2. A force exerted by the channel pointing from q to O.
   3. A force in the direction of motion.
   4. A force pointing from O to q.

   Which of the above forces is (are) acting on the ball when it is within the frictionless channel at position "q"?

   (A) 1 only.
   (B) 1 and 2.
   (C) 1 and 3.
   (D) 1, 2, and 3.
   (E) 1, 3, and 4.

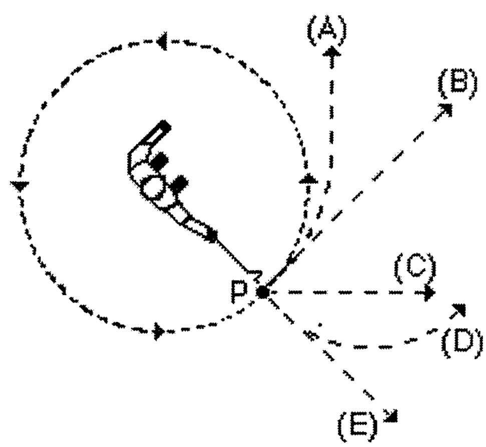
6. Which path in the figure at right would the ball most closely follow after it exits the channel at "r" and moves across the frictionless table top?




7. A steel ball is attached to a string and is swung in a circular path in a horizontal plane as illustrated in the accompanying figure.

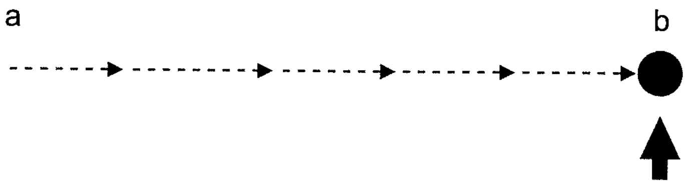
   At the point P indicated in the figure, the string suddenly breaks near the ball.

   If these events are observed from directly above as in the figure, which path would the ball most closely follow after the string breaks?

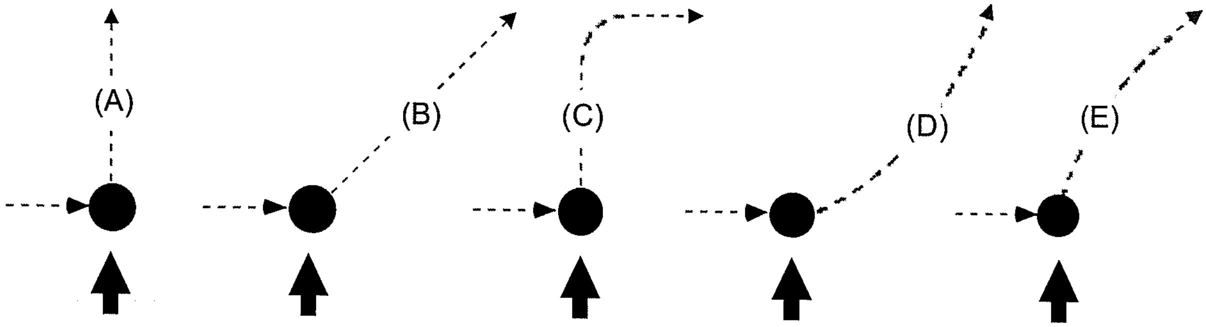


**USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (8 through 11).**

The figure depicts a hockey puck sliding with constant speed $v_o$ in a straight line from point "a" to point "b" on a frictionless horizontal surface. Forces exerted by the air are negligible. You are looking down on the puck. When the puck reaches point "b," it receives a swift horizontal kick in the direction of the heavy print arrow. Had the puck been at rest at point "b," then the kick would have set the puck in horizontal motion with a speed $v_k$ in the direction of the kick.




8. Which of the paths below would the puck most closely follow after receiving the kick ?

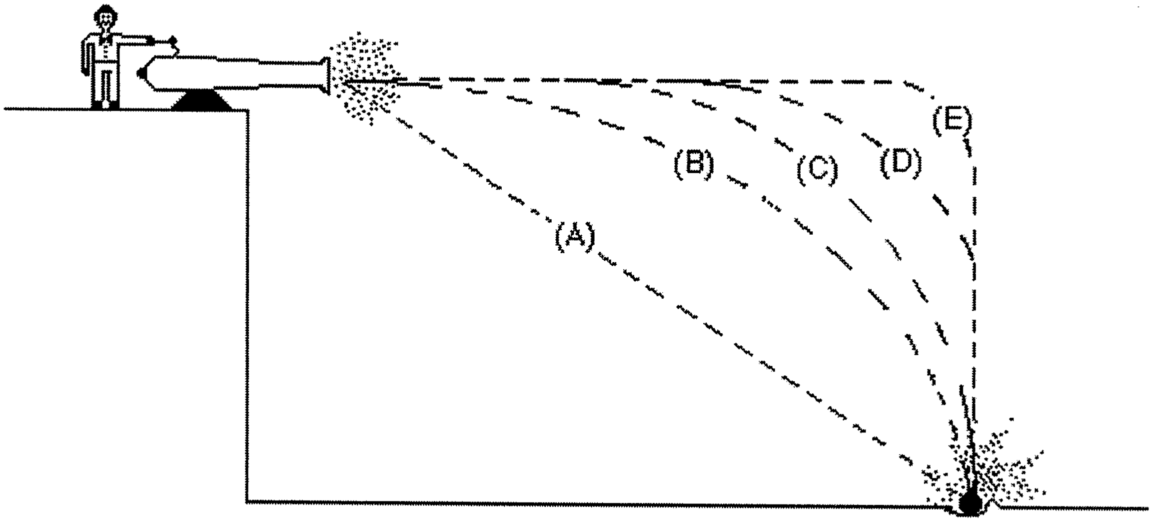



9. The speed of the puck just after it receives the kick is:
   (A) equal to the speed "$v_o$" it had before it received the kick.
   (B) equal to the speed "$v_k$" resulting from the kick and independent of the speed "$v_o$".
   (C) equal to the arithmetic sum of the speeds "$v_o$" and "$v_k$".
   (D) smaller than either of the speeds "$v_o$" or "$v_k$".
   (E) greater than either of the speeds "$v_o$" or "$v_k$", but less than the arithmetic sum of these two speeds.

10. Along the frictionless path you have chosen in question 8, the speed of the puck after receiving the kick:
    (A) is constant.
    (B) continuously increases.
    (C) continuously decreases.
    (D) increases for a while and decreases thereafter.
    (E) is constant for a while and decreases thereafter.

11. Along the frictionless path you have chosen in question 8, the main force(s) acting on the puck after receiving the kick is (are):
    (A) a downward force of gravity.
    (B) a downward force of gravity, and a horizontal force in the direction of motion.
    (C) a downward force of gravity, an upward force exerted by the surface, and a horizontal force in the direction of motion.
    (D) a downward force of gravity and an upward force exerted by the surface.
    (E) none. (No forces act on the puck.)

12. A ball is fired by a cannon from the top of a cliff as shown in the figure below. Which of the paths would the cannon ball most closely follow?




13. A boy throws a steel ball straight up. Consider the motion of the ball only after it has left the boy's hand but before it touches the ground, and assume that forces exerted by the air are negligible. For these conditions, the force(s) acting on the ball is (are):

(A) a downward force of gravity along with a steadily decreasing upward force.

(B) a steadily decreasing upward force from the moment it leaves the boy's hand until it reaches its highest point; on the way down there is a steadily increasing downward force of gravity as the object gets closer to the earth.

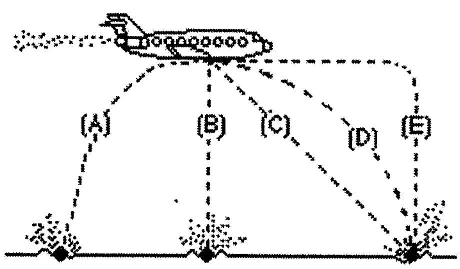
(C) an almost constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point; on the way down there is only a constant downward force of gravity.

(D) an almost constant downward force of gravity only.

(E) none of the above. The ball falls back to ground because of its natural tendency to rest on the surface of the earth.

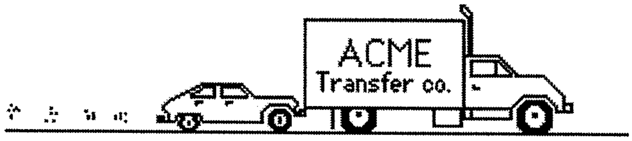
14. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction.

As observed by a person standing on the ground and viewing the plane as in the figure at right, which path would the bowling ball most closely follow after leaving the airplane?



**USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT TWO QUESTIONS (15 and 16).**

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




15. While the car, still pushing the truck, is speeding up to get up to cruising speed:
    (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
    (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
    (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
    (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot 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.

16. After the car reaches the constant cruising speed at which its driver wishes to push the truck:
    (A) the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car.
    (B) the amount of force with which the car pushes on the truck is smaller than that with which the truck pushes back on the car.
    (C) the amount of force with which the car pushes on the truck is greater than that with which the truck pushes back on the car.
    (D) the car's engine is running so the car pushes against the truck, but the truck's engine is not running so the truck cannot 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.

17. An elevator is being lifted up an elevator shaft at a constant speed by a steel cable as shown in the figure below. All frictional effects are negligible. In this situation, forces on the elevator are such that:

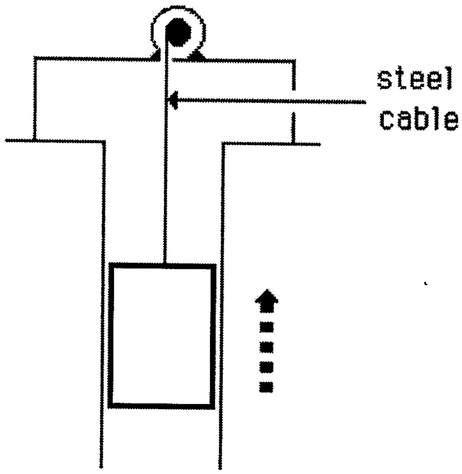
(A) the upward force by the cable is greater than the downward force of gravity.

(B) the upward force by the cable is equal to the downward force of gravity.

(C) the upward force by the cable is smaller than the downward force of gravity.

(D) the upward force by the cable is greater than the sum of the downward force of gravity and a downward force due to the air.

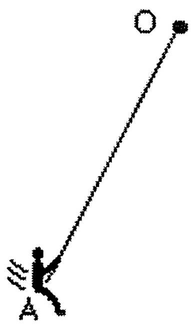
(E) none of the above. (The elevator goes up because the cable is being shortened, not because an upward force is exerted on the elevator by the cable).




Elevator going up
at constant speed

18. The figure below shows a boy swinging on a rope, starting at a point higher than A. Consider the following distinct forces:

1. A downward force of gravity.
2. A force exerted by the rope pointing from A to O.
3. A force in the direction of the boy's motion.
4. A force pointing from O to A.




Which of the above forces is (are) acting on the boy when he is at position A?

(A) 1 only.

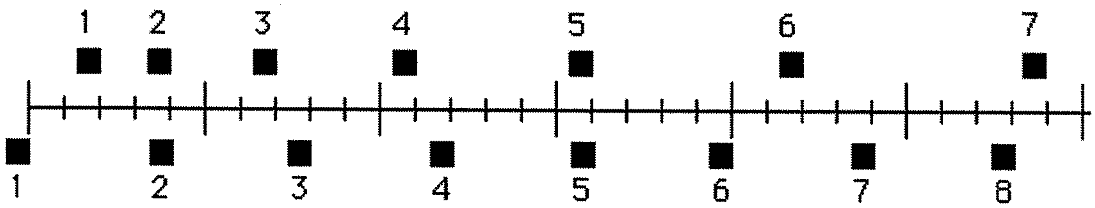
(B) 1 and 2.

(C) 1 and 3.

(D) 1, 2, and 3.

(E) 1, 3, and 4.

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




Do the blocks ever have the same speed?

(A) No.

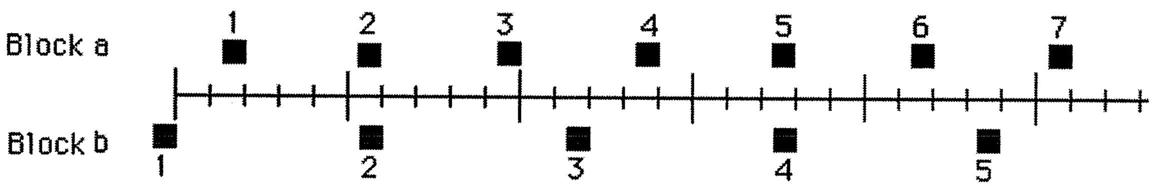
(B) Yes, at instant 2.

(C) Yes, at instant 5.

(D) Yes, at instants 2 and 5.

(E) Yes, at some time during the interval 3 to 4.

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




The accelerations of the blocks are related as follows:

(A) The acceleration of "a" is greater than the acceleration of " b".

(B) The acceleration of "a" equals the acceleration of "b". Both accelerations are greater than zero.

(C) The acceleration of "b" is greater than the acceleration of "a".

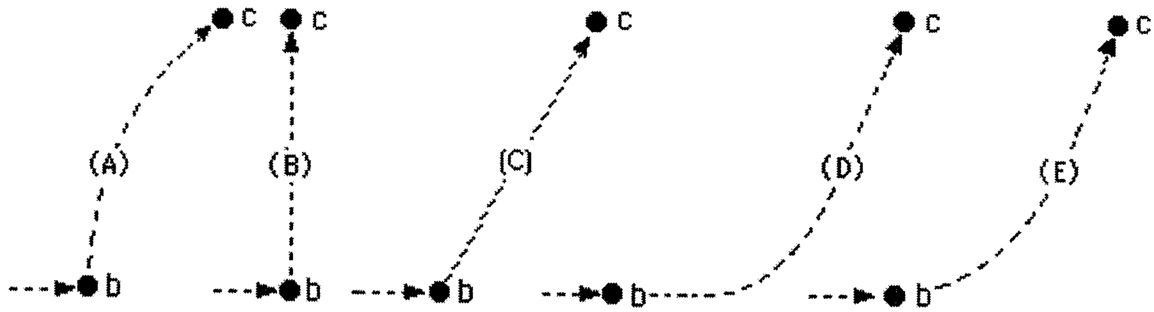
(D) The acceleration of "a" equals the acceleration of "b". Both accelerations are zero.

(E) Not enough information is given to answer the question.

**USE THE STATEMENT AND FIGURE BELOW TO ANSWER THE NEXT FOUR QUESTIONS (21 through 24).**

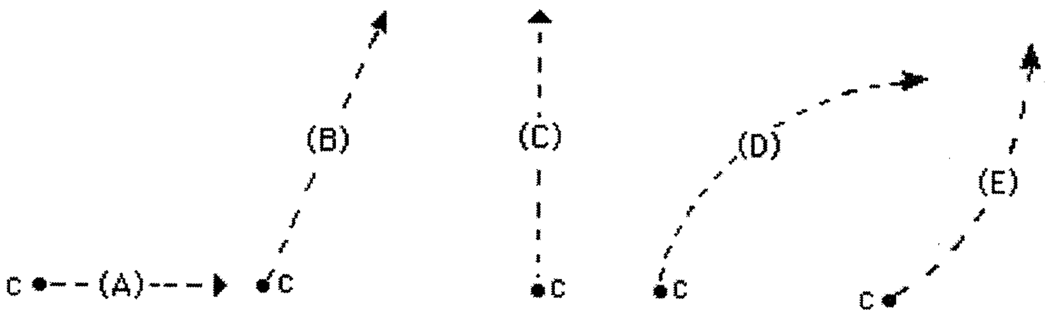
A rocket drifts sideways in outer space from point "a" to point "b" as shown below. The rocket is subject to no outside forces. Starting at position "b", the rocket's engine is turned on and produces a constant thrust (force on the rocket) at right angles to the line "ab". The constant thrust is maintained until the rocket reaches a point "c" in space.


21. Which of the paths below best represents the path of the rocket between points "b" and "c"?




22. As the rocket moves from position"b" to position "c" its speed 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.

23. At point "c" the rocket's engine is turned off and the thrust immediately drops to zero. Which of the paths below will the rocket follow beyond point "c"?




24. Beyond position "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.

25. A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed "$v_0$".

The constant horizontal force applied by the woman:

(A) has the same magnitude as the weight of the box.

(B) is greater than the weight of the box.

(C) has the same magnitude as the total force which resists the motion of the box.

(D) is greater than the total force which resists the motion of the box.

(E) is greater than either the weight of the box or the total force which resists its motion.

26. If the woman in the previous question doubles the constant horizontal force that she exerts on the box to push it on the same horizontal floor, the box then moves:

(A) with a constant speed that is double the speed "$v_0$" in the previous question.

(B) with a constant speed that is greater than the speed "$v_0$" in the previous question, but not necessarily twice as great.

(C) for a while with a speed that is constant and greater than the speed "$v_0$" in the previous question, then with a speed that increases thereafter.

(D) for a while with an increasing speed, then with a constant speed thereafter.

(E) with a continuously increasing speed.

27. If the woman in question 25 suddenly stops applying a horizontal force to the box, then the box will:

(A) immediately come to a stop.

(B) continue moving at a constant speed for a while and then slow to a stop.

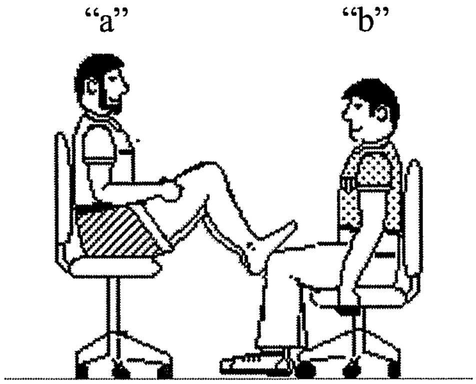
(C) immediately start slowing to a stop.

(D) continue at a constant speed.

(E) increase its speed for a while and then start slowing to a stop.

28. In the figure at right, student "a" has a mass of 95 kg and student "b" has a mass of 77 kg. They sit in identical office chairs facing each other.

Student "a" places his bare feet on the knees of student "b", as shown. Student "a" then suddenly pushes outward with his feet, causing both chairs to move.




During the push and while the students are still touching one another:

(A) neither student exerts a force on the other.

(B) student "a" exerts a force on student "b", but "b" does not 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.

29. An empty office chair is at rest on a floor. Consider the following forces:

1. A downward force of gravity.
2. An upward force exerted by the floor.
3. A net downward force exerted by the air.

Which of the forces is (are) acting on the office chair?

(A) 1 only.

(B) 1 and 2.

(C) 2 and 3.

(D) 1, 2, and 3.

(E) none of the forces. (Since the chair is at rest there are no forces acting upon it.)

30. Despite a very strong wind, a tennis player manages to hit a tennis ball with her racquet so that the ball passes over the net and lands in her opponent's court.
Consider the following forces:

1. A downward force of gravity.
2. A force by the "hit".
3. A force exerted by the air.

Which of the above forces is (are) acting on the tennis ball after it has left contact with the racquet and before it touches the ground?

(A) 1 only.

(B) 1 and 2.

(C) 1 and 3.

(D) 2 and 3.

(E) 1, 2, and 3.

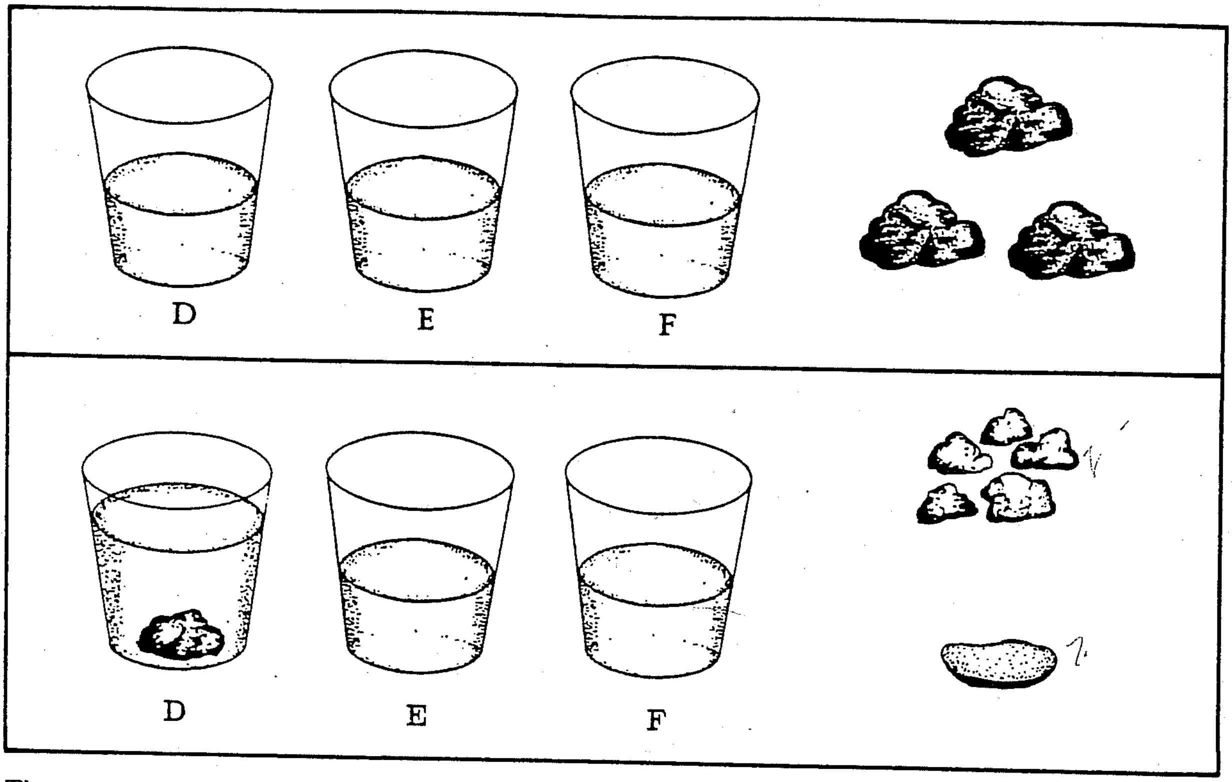
# ABRIDGED TEST of FORMAL REASONING

Directions:

Do not write anything on questionnaire.
Mark your responses on the OPSCAN sheets with a HB pencil
If you change your answer, complete erase the unwanted response
Fill in your ID number and your section number

Read each question carefully and choose the best answer that reflects your thinking

Thank you for participating in this study




Three cups, (Cup D, Cup E, and Cup F) are partially filled with water. Beside the three cups are three balls of clay. These three balls are exactly the same size as each other. The first ball is placed in Cup D as shown. The water level in Cup D rises. Before placing the second ball into Cup E, it is flattened into a pancake shape as shown. The third ball of clay is broken into five pieces as shown and then placed into Cup F.

1. What do you think will happen to the water level in Cup E when this pancake shaped piece of clay is placed into it?

   A. The water level will rise up higher than the level in cup D.
   B. The water level will rise to half the level of cup D.
   C. The water level will go up to the same height as that in cup D.
   D. The water level will rise to one–fifth the height of that in cup D.

2. What is the reason for your answer to the question just above?

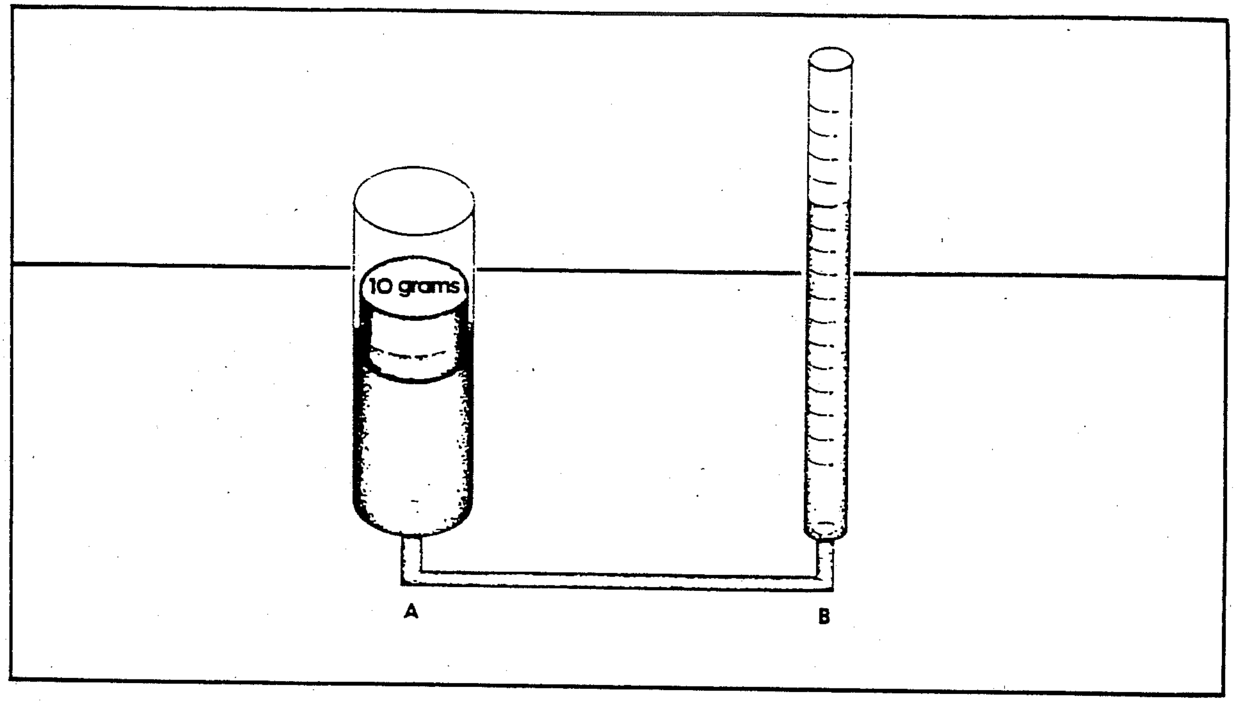
   A. The pancake shape takes up more space.
   B. The balls were the same size at the start.
   C. The pancake shape is flat and therefore it takes up less space.
   D. The ball and pancake weigh the same.

3. What do you think will happen to the water level in Cup F when the five small balls of clay are placed in it?

   A. The water level will go up to the same height as that in Cup D.
   B. The water level will NOT rise up as high as that in Cup D.
   C. The water level will rise up higher than the level in Cup D.
   D. The water level will rise one–fifth the height as that in Cup D.

4. What is the reason for your answer to the question just above?

   A. The five balls of clay take up more space.
   B. The balls were the same size before the one ball was broken into pieces.
   C. The five small balls take up less room.
   D. The five small balls weigh the same as the one large ball.




When weights are placed on the top of the water in jar A, the weights push down on the water and force the water up the thin glass pipe B. The greater the weight on A, the higher the column of water in B.

5. If the weight on A is doubled, what will happen to the height of the column of water in B?

   A. It will go up to a height 50 percent greater than before.
   B. It will go up twice the height of before.
   C. It will stay the same.
   D. It will be lower by one-half the height.

6. The water is replaced by a liquid that is more dense than water. What will happen to the height of the column of liquid in B if the same weight is applied to A as in the question above?

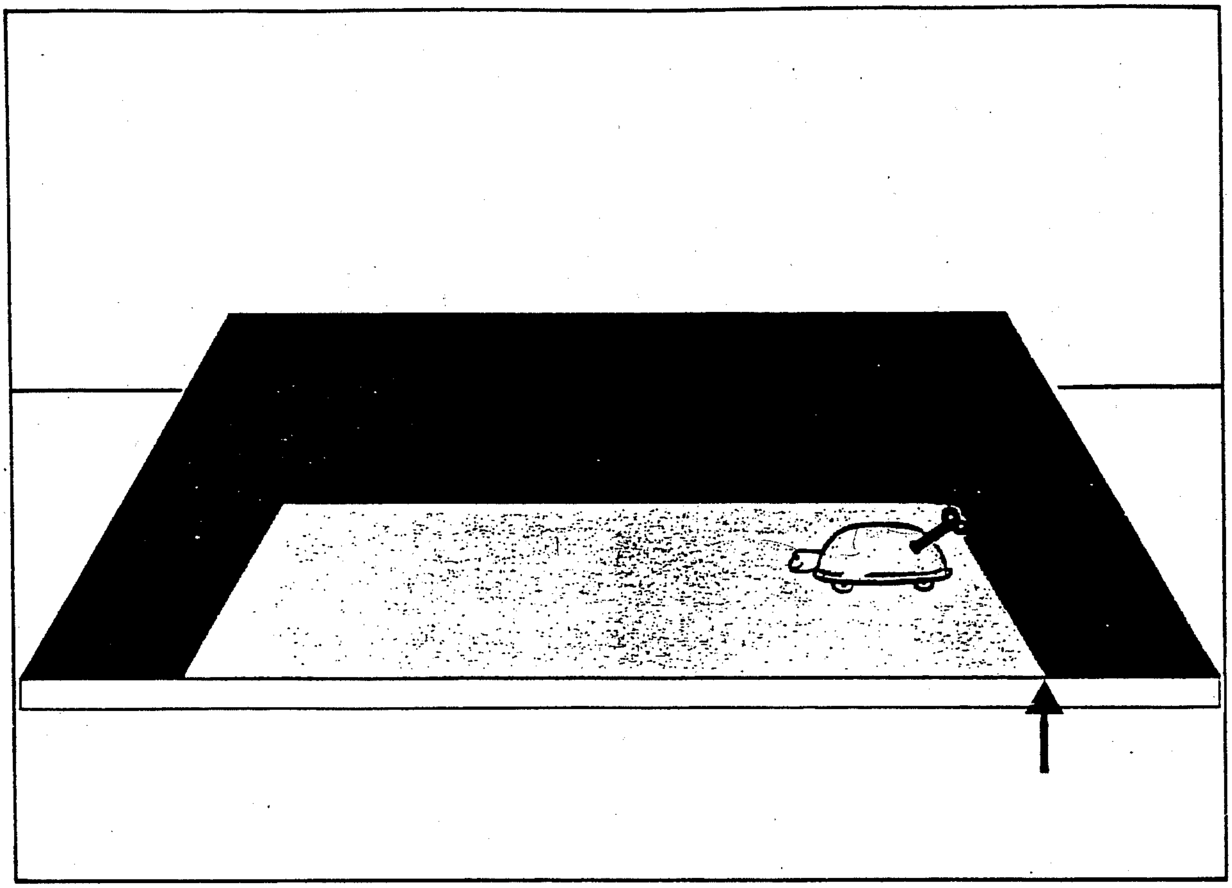
   A. It will go up to a height 50 percent greater than in the previous question.
   B. It will go up higher than in the previous question.
   C. It will be lower than the level it achieved in the previous question.
   D. It will go up to the same height as in the previous question.

7. What is the reason for your answer to the question just above (the second question)?

   A. The liquid is denser, so more weight will be required to push it up to the same level.
   B. The liquid will always go to the top no matter how hard the weight pushes on the liquid.
   C. The type of liquid does not affect how far the column will rise. Only the weight affects this.
   D. The liquid is denser and so the column will rise higher.

8. The weight on the denser liquid is now four times what it was originally. What will happen to the column of liquid in B?

   A. It will go up to a height double that in the second question.
   B. It will go up four times as high as it did in the second question.
   C. It will go to the same height as it did in the second question.
   D. The additional weight will NOT affect the height of the column in B.



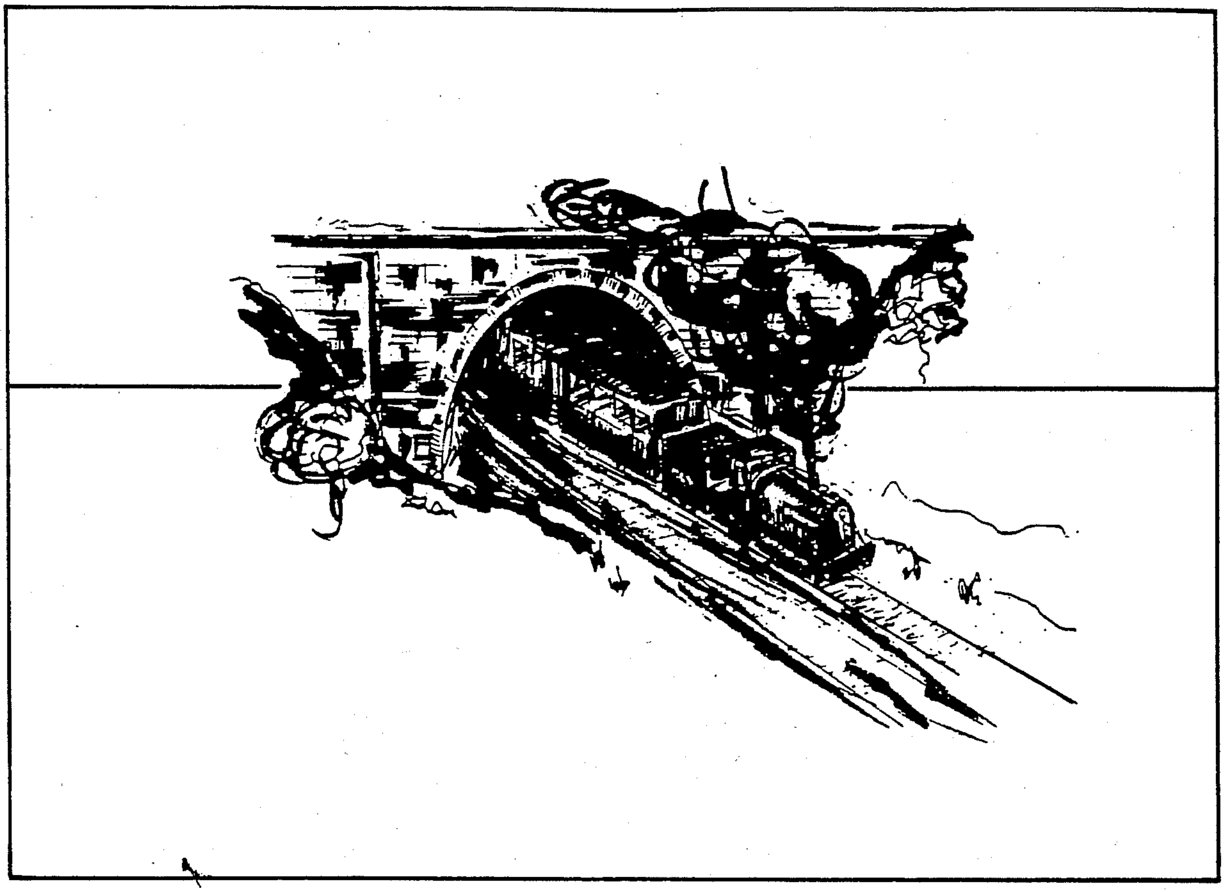
A small toy wind-up turtle is placed on a shaded strip of paper. The paper strip is lined up along the edge of a board as shown in the picture. The turtle can be moved along the paper strip. The paper strip can also be moved along the board. Both the toy and the paper strip can be moved forward or backward. The toy, the end of the paper strip, and the starting point on the board are all lined up as shown.

9. If the turtle moves forward at the same speed that the paper strip moves backward, how far will the turtle be from the starting point after a short time (as long as the turtle is still on the strip of paper)?

A. It would be at the starting point.
B. One-fourth the distance of the paper strip from the starting point.
C. Double the distance of the paper strip from the starting point.
D. It would be behind the starting point.

10. If the turtle moves forward at 1/3 the speed that the paper strip moves backward, where would the turtle be after a short period of time (as long as the turtle is still on the strip of paper)?

A. Three times as far forward as the paper strip is backward from the starting point.
B. One-third the distance in front of the starting point as the paper strip is behind the starting point.
C. It would be behind the starting point.
D. As far in front of the starting point as the end of the paper strip is in back of it.



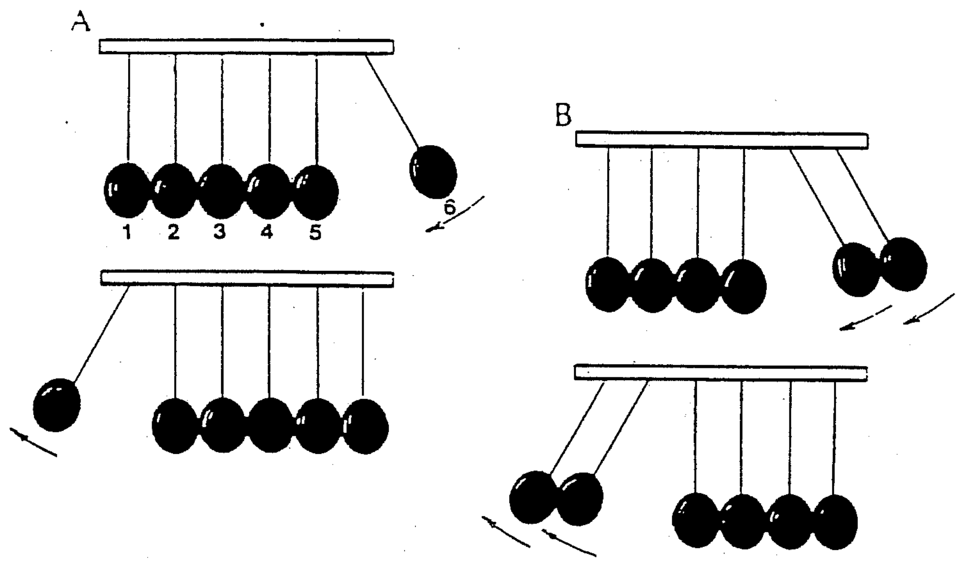
Two people are sitting on this train as it passes through a long tunnel in the side of a mountain. Mr. Red (R) is sitting at the front of the train and Mr. Blue (B) is sitting at the back of the train. For the following two situations, decide whether Mr. R and Mr. B will stay in the tunnel for the same amount of time.

11. SITUATION 1: After the train enters the tunnel Mr. R gets up from his seat in the front, and walks back to sit with Mr. B. How much time altogether will Mr. R spend in the tunnel?

A. Less time in the tunnel than Mr. B.
B. Twice the time in the tunnel as Mr. B.
C. The same amount of time in the tunnel as Mr. B.
D. More time in the tunnel than Mr. B.

12. SITUATION 2: After the train has entered the tunnel, Mr. B gets up from his seat in the back. He walks forward to sit with Mr. R. Halfway on his trip forward, he decides to go back to his seat for his paper. He gets his paper and then goes forward again and joins Mr. R, while the train is still in the tunnel. How much time did Mr. B spend in the tunnel?

A. Less time in the tunnel than Mr. R.
B. More time in the tunnel than Mr. R.
C. One-and-one-half as much time in the tunnel as Mr. R.
D. The same amount of time in the tunnel as Mr. R.



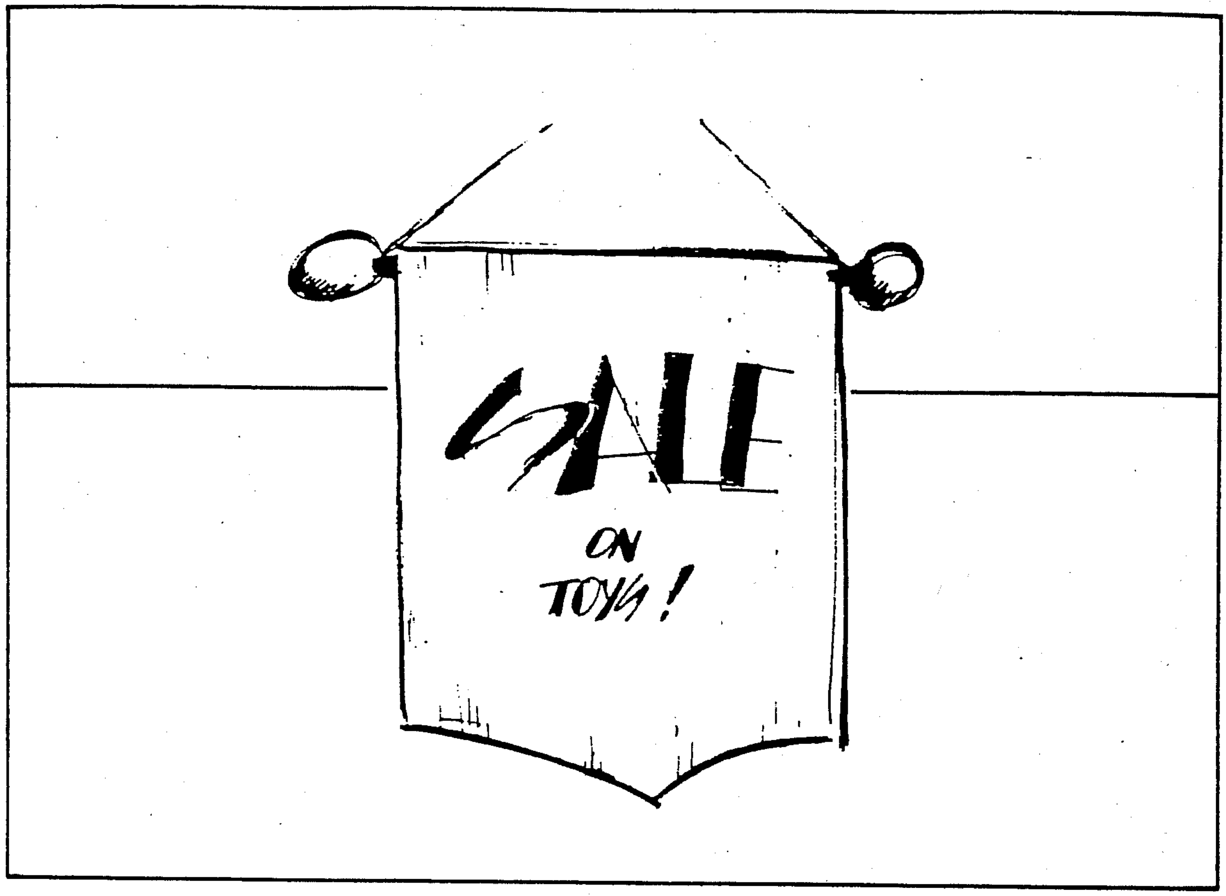

A few years ago there were several games in department stores which were for business executives, to calm their nerves. One such game is pictured above. Six plastic balls are hung from a support bar. When the ball marked 6 is pulled back and then let go, it swings forward and hits ball 5. When this happens, ball 1 swings forward and back while the balls numbered 2-6 do not move. If balls 5 and 6 are pulled back and then let go, balls 1 and 2 swing forward and back. Balls 3 and 4 do not move.

13. If balls 3, 4, 5, and 6 are pulled back and then let go, which balls will swing out?

A. Balls 1, 2
B. Balls 1, 2, 3
C. Balls 1, 2, 3, 4
D. Balls 1, 2, 3, 4, 5, 6

14. What is the reason for your answer to the question above?

A. Only the balls that were not pulled back would swing out.
B. Balls 4, 5, 6 would transfer their energy to ball 3 which would swing out and push out balls 1 and 2 in front of it.
C. All would swing out because more balls are pulled back than are left to be hit.
D. Since only four balls were pulled back and then let go, only that number would swing out.




A local toy manufacturer explained to one of his friends that no matter what he charges, the quantity he sells always goes up and down in relation to that price. The result is that the total revenue (money he takes in) is constant (remains the same). For example, if he raises his price, his sales decrease just enough so that the revenue is kept constant. Just the opposite happens if he lowers his price. His present cost per toy is constant no matter how many toys he produces. He wants to know how he should change the way he runs his toy business so that he can make the most profit.

15 What can he do to make the most profit?

A. There is nothing he can do because the total revenue remains constant.
B. Pick a price that is right in the middle so demand is high but he can meet the demand.
C. Increase the quantity of toys sold.
D. Reduce the cost of producing the toys.

16. If the toy manufacturer were to double the number of toys that he made with no change in his cost per toy, what would happen to his profit?

A. It would be cut in half.
B. It would remain the same.
C. It would double.
D. It would be four times as great.