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Physics Knowledge and Real-World Knowledge: An Underdeveloped Link

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ABSTRACT

For experienced physicists, real-world knowledge and physics knowledge are inseparable, but for novices the two knowledge stores are often only sporadically and tenuously connected. Evidence will be reported from studies indicating that for students physics language does not always describe or evoke real-world behavior, nor do real-world situations always evoke physics concepts. In particular, a study of students' written explanations to "what if..?" questions in elementary mechanics provided data on the types of explanations students produce as output, including substantial use of everyday language. A follow-up study presented students with pairs of pre-written explanations to these questions and asked them to indicate their preferences. We found that not only do students prefer more formal types of explanations to "intuitive" explanations written in everyday language, they had greater difficulty recognizing when "intuitive" explanations were correct.

INTRODUCTION

In the teaching of introductory physics, and in research on physics learning as well, a preponderant emphasis has been placed on successful problem-solving both as a final goal and as a measure of competence. But the ways in which individuals produce and respond to explanations can provide information about the content and structure of an individual's knowledge store which is not necessarily evident in the individual's problem solutions.

Explanations are certainly a measure by which experts assess one another. Well structured and conceptually sound explanations are highly valued in colleagues, whether in informal communication between collaborators, the mutual teaching that takes place in seminars and colloquia, or the communication of results at professional meetings and in journals. The valuing depends as well on the expert's complementary ability to comprehend explanations. Beginning physics students, in contrast, tend to be poor explainers (Chi, Feltovich, and Glaser 1981; Touger, Dufresne, Gerace, and Mestre, 1987), and in the usual course of introductory physics instruction are all too infrequently called upon to provide qualitative explanations. Nor are they usually called upon to go beyond algebraic manipulation to demonstrate what they have understood from explanations presented to them by instructors or textbooks.

The salient differences in the types of explanations generated by experts and novices are related to differences in the way experts and novices organize their knowledge in memory, and use this knowledge to solve problems. Experts' memory store tends to be organized hierarchically, with fundamental concepts at the top, followed by ancillary concepts, and equations and facts near the bottom (Chi and Glaser 1981; Glaser, 1992; Mestre, 1991, in press; Heller & Reif, 1984; Silver & Marshall, 1990). Their knowledge store tends to be dense and richly interconnected, allowing experts to access information quickly and efficiently. When solving problems, experts tend to proceed top down from fundamental principles and concepts in hierarchical fashion, whereas novices typically hunt for equations without a guiding overview (Chi et al., 1981; Larkin, 1980).Novices tend to store knowledge homogeneously and lack the rich interconnection possessed by experts. Experts have extensive procedural knowledge, and use multiple representations that are strongly interconnected. Novices' procedural knowledge tends to be limited, and their connections between representations are weak or absent (Glaser, 1992). In particular, as will be shown, they lack secure connections among what are for them the largely separate domains of physics concepts, real world knowledge, and descriptive language.

Given these differences, it is not surprising that novices' explanations of how to solve problems are frequently equation-centered and somewhat disorganized, or rely on everyday parlance riddled with ambiguity. In contrast, experts' explanations are logically structured, describing the concepts that need to be applied and a general procedure for applying them (Chi *et al*., 1981; Touger *et al*., 1987).

Since we were interested in what connections novices make or fail to make, we chose to maximize subjects' opportunities for making connections by asking them to deal with explanations of phenomena in open-ended contexts in which there is not a well-framed problem requiring application of a standard algorithm. In particular, we investigated the types and attributes of explanations subjects would generate about what happens in physical situations when the subject is not asked to focus on a particular quantity. We were also interested in how students would react when presented with explanations to such situations.

The studies reported here address these two broad issues. More specifically, we report here on two experiments. The first of these examines written explanations that beginning physics students generate in response to open-ended problem <u>situations</u>. Examining the explanations generated by subjects in response to open-ended physical situations should provide insights into the type of knowledge they are able to draw on in unstructured qualitative contexts. In the second experiment we examine subjects' preferences among explanations of physical situations presented to them. A mismatch between the type of explanation a subject generates and the type of explanation he or she prefers would suggest an inability to draw on his or her knowledge store to generate a presumably superior explanation. Both experiments were carried out within a broader, multifaceted study, Connections with the broader study are reported elsewhere (Mestre, Dufresne, Gerace, Hardiman, and Touger, 1992, 1993; Touger, Dufresne, Gerace, Hardiman, and Mestre, in press). The experiment in which subjects generated their own explanations will hereafter be called the Explanation Generation Experiment; the experiment in which they judged explanations provided to them will be called the Explanation Judgment Experiment.

THE EXPLANATION GENERATION EXPERIMENT: QUESTIONS AND METHOD

The Explanation Generation Experiment addressed two broad questions:

(i.1) What are the salient characteristics of novices' explanations to open-ended problem situations?

(i.2) How does their performance in generating explanations correlate with their performance on other measures of competence?

In this experiment, subjects were presented with six questions, three answered during each of two sessions, requiring written explanations of physical situations. Each question presented the subject with a physical set-up and asked the subject to explain what happens when a particular change is made in the set-up. The questions are shown in Figure 1. In each question, subjects are free to address whatever variables and to apply whatever principles or concepts they think are relevant. The protocol directed subjects to write out explicitly the reasoning by which they reached their conclusions. Since subjects were not asked to solve for a specific variable or quantity, the extent to which equations were used in the explanations was entirely at the subject's own discretion. Subjects were allotted a half hour to answer three questions.

The Generation Experiment was administered to 45 subjects, recruited from a pool of students who had passed a semester-long calculus-based mechanics course at the University of Massachusetts with a grade of B or better during the previous semester. Figure 1 shows the two sets of three questions, labeled A and B in the figure, that were administered. “Half" of the 45 subjects answered Set A in the first session and Set B in the second, whereas the other “half” answered the two sets of questions in reverse order. At least some asects of each question were amenable to treatment by work and/or energy concepts, allowing us to assess the degree of structured use of such concepts. Two questions in Set A (A1 and A2) involved the same set-ups as parallel questions in Set B (B1 and B2 respectively), allowing us to focus on subtleties of context dependence and the scope of applicability of concepts.

To investigate question (i.1) above we examined the characteristics of explanations generated by subjects during both sessions. In addition, ten of the subjects were subsequently interviewed to help us understand the thinking that went into their written explanations; each interview was about one-half hour in length. To investigate question (i.2), we drew on data collected in the broader project of which this experiment was a part. The broader project sought to foster more structured problem solving by having students work with a hierarchically structured, menu driven problem solving tool. The two explanation sessions were administered before ("pre") and after ("post") this treatment, along with other pre and post tests. We report the results relating to question (i.2) elsewhere (Mestre *et al.*, 1992, 1993). The impact of treatment on students' explanations are likewise reported and discussed in detail elsewhere (Mestre *et al.*, 1993; Touger *et al.*, in press). In this paper we will address the characteristics of students' explanations that were common to both the pre- and post-sessions.

THE EXPLANATION GENERATION EXPERIMENT: RESULTS AND DISCUSSION

Context dependence and misconceptions: Because of the latitude of response afforded by the "what if. . " questions, the Generation Experiment yielded considerable evidence of context dependence in the variables subjects chose to address and in the concepts they applied. For example, in dealing with questions asking how a certain change "affected the motion of an object", subjects tended to focus only on the distance traveled or only on the velocity at some point, depending on the context. Complete data on which variables are evoked by which context are presented and discussed elsewhere (Touger *et al.*, 1987; Touger *et al.*, in press). It is worth noting, however, that for the expert distance and velocity are interrelated either by conservation of mechanical energy or by the work-energy theorem in all of these contexts. The virtually unavoidable connectedness of the two variables that these governing concepts provide is missing for most novices. Not surprisingly, the students linked energy-related concepts far less readily to situations than would experts.

From the array of context dependence data, we will focus here on one particular case. In treating a block sliding from a smooth onto a rough surface, 14 of 22 pre-test respondents addressed velocity, and 7 addressed distance. Of these, only 2 addressed both. Similarly, in an earlier pilot study, of 8 respondents to this question, 7 addressed velocity, 1 addressed distance, and none addressed both. The pilot study showed almost no pre-to-post change. In the main study, there was a major pre-to-post change because during treatment in the larger project, the subjects had been given a problem asking for the distance a body traveled on a rough surface.

Students' use of vocabulary was context-dependent, many more using "acceleration" explicitly in reference to the gravitational situation than in the case of the block sliding onto a rough surface, where language like "slows down faster" was used. Consistent with Rosch's (1977) notions on categorization, we suggest that a set of appropriate contexts forms part of the meaning of a word such as "acceleration". For the expert, the word in the descriptive language domain is linked to both the formal definition in the physics concepts domain and the instances in the domain of real-world knowledge. For the novice, some of those instances, such as objects slowing down, have not been sufficiently assimilated into the set of instances to which "acceleration" applies to evoke use of that word.

Students' explanations exhibited a profusion of the misconceptions or naive conceptions that have for the most part been reported elsewhere (e.g., McDermott, 1984; Mestre and Touger, 1989). One, not reported by other investigators, is of particular relevance here.

We wondered why relatively few students addressed the distance the block travels in the rough region. A number of students' written explanations stated, with superficial correctness, that "the block is slowed down even more" when the coefficient of friction in the rough region is increased. In interviews, two of these students were asked to describe the motion of the block by moving a finger along the table. Rather than slowing gradually to a stop in the rough region, their fingers appeared to drop almost instantaneuosly to a lower speed upon entering the rough region and then continue without further change in speed. Any uncertainty that this is what they were doing was dispelled by their responses to subsequent questions:

Student 1: "Once it's on the rough surface [the velocity] should stay about the same — I mean not the same as on the smooth surface but. . . I would assume it would be constant once it's on there."

Student 2: "I would think it would go from a faster speed in the smooth region to a slower speed in the rough region. It wouldn't necessarily have to stop."

These students did not talk about the distance the block went because it is meaningless to do so for a block that does not stop! They were perhaps untroubled by this because they had learned too well that in the idealized world of the physicist, moving objects can keep going forever. They did not routinely check physics knowledge against real world or "common sense" expectations about how things behave.

Types of explanation: It was found that although not all student explanations can be readily classified, many of them fell into three broad (and occasionally overlapping) types:

- Formula-driven: Explanations of this type proceed with a considerable amount of algebraic manipulation from formulas. The formulas, usually written down at the outset, apparently result from an initial memory search in response to a given question. Diagrams are sometimes similarly treated. Often the subsequent narrative fails to use or even refer to the initial equations or diagrams, an indication of the lack of interconnectedness, particularly among different representations, in the novice's knowledge store.

- Intuitive: These explanations, usually qualitative, discuss the given set-up largely in everyday or "real world" terms. Phrases like “impact”,“slowing down”, and “not going as far” predominate over formal physics language, which is used minimally.
- Hierarchical: These, the most expert-like explanations, clearly identify relevant governing concepts and apply them in relatively structured ways, such as identifying initial and final states for energy conservation. At best, they involve integration of mathematical and visual representations with related narrative, displaying expert-like ability to use multiple representations.

Of a total of 253 explanations, 77 (30%) were Formula-driven, 77 (30%) were Intuitive, and 54 (21%) were Hierarchical. The Intuitive explanations may be more of a default response, whereas the Hierarchical and Formula-driven approaches are more likely learned in physics courses. Although as teachers we would like the transition to be to Hierarchical, this is not necessarily what happens. Subjects who failed to integrate equations with narrative sometimes expressed discomfort with the question format because it did not ask about specific variables. One subject who began by “sort of doodling, just trying to remember different formulas . . . that had variables that I was looking for” was puzzled by the absence of numerical values that she could plug into an equation to generate an answer, as had been the accustomed situation on her course exams. At one point she comments, “I knew what affected it but they weren't given so I didn't know how to correlate what was given. On that one [a projectile motion situation] I thought about the velocity but they didn't say anything about time. . . and the equation there [she had written $s = v_0 t + \frac{1}{2} a t^2$] had a variable t in it.”

This student, like too many others, had learned that the way to deal with a problem was to find suitable equations to connect the value of an unknown quantity to given values of other quantities. This approach is unfortunately encouraged by some teachers. The student becomes accustomed to working wholly within the mathematical representation without thinking of it as a model for, or connecting it wholly with, the actual physical situation. As this student's efforts show, attempting to carry over this approach from problem-solving to explanation is likely to lead to failure and discouragement..

The predominance of three principal types of explanations motivated the Judgment Experiment.

THE EXPLANATION JUDGMENT EXPERIMENT: QUESTIONS AND METHOD

The Judgment Experiment was conceived as a consequence of our finding that certain types of explanations written by students were recurrent. We wondered whether the types of explanations students wrote were the types they preferred or whether those types were default options, written when the student was unable (or unable with the same level of effort) to do anything else. This led to the design and administration of an explanation preference task, focusing on the three recurrent (and sometimes overlapping) types of explanation which we observed in the Generation Experiment: Formula-driven, Intuitive, and Hierarchical.

The Judgment Experiment addressed the following questions:

(ii.1) What kinds of explanations do students prefer?

(ii.2) Are they less likely to choose a correct explanation if it is counter to preference type?

We were also interested in what broader implications their type preferences might have.

The explanations preference task was administered to 20 subjects meeting the same criteria as the subjects in the Generation Experiment, but not including any of those participants. In this task, subjects were presented with written explanations of five "what if...?" situations, including some of the situations in Sets A and B in the Generation Experiment, and others of the same genre. These explanations, although written by the author especially for the task, were modeled where possible on actual novice and expert[1] output from the Generation Experiment. They included six explanations of each situation, two -- one correct and one incorrect -- in each of the three categories noted above. Sample explanations of each type appear in the Appendix.

The paradigm consisted of presenting the subject with a "what if...?" question, and side by side beneath it two explanations differing in type, degree of correctness, or both. The subjects were told that "...Sometimes the explanations will differ in their conclusions; sometimes they will differ only in their approach", and were asked to check the explanation they preferred.

A Latin square pattern of administration, shown in Table 1, was followed. Each square indicates which comparisons each student in a group of five (numbered S1 to S5) is to make for each of five questions (numbered Q1 to Q5). The same pattern was administered to two groups of five subjects with X = Formula-driven and to two groups of five subjects with X = Intuitive (hence 20 subjects in all). Thus, a particular group of five students would be considering only Hierarchical (correct or incorrect) and Intuitive (correct or incorrect) explanations, or only Hierarchical and Formula-driven explanations. Note that although a particular group of five students would be considering two types of explanations, two of the same type might be paired together for a judgment comparison (e.g., Hierarchical correct with Hierarchical incorrect). Because the number of student subjects available was limited, no direct comparisons of Intuitive and Formula-driven explanations were made.

THE EXPLANATION JUDGMENT EXPERIMENT: RESULTS AND DISCUSSION

The results of the Judgment Experiment are tabulated in Table 2. Combining correct and incorrect choices, we found that on Hierarchical (H) vs. Intuitive (I) comparisons, 23/30 choices were Hierarchical, and that on Hierarchical (H) vs. Formula-driven (F) comparisons, 18/30 choices were Hierarchical. In the latter comparisons, 8/10 subjects chose H 2/3 times, and the remaining 2/10 chose H 1/3 times. The choice was H significantly greater than 50% of the time whether analyzed by subject ($t(8) = 10.0$, $p < .0001$ for H vs. I comparisons, and $t(9) = 13.5$, $p < .0001$ for H vs. F comparisons) or by question ($t(9) = 3.75$, $p < .005$ for H vs. I, and $t(9) = 7.22$, $p < .0001$ for H vs. F). The preference for Hierarchical was slightly stronger vs. Intuitive than vs. Formula-driven ($t(18) = 1.99$, $p = .06$).

For comparisons of correct vs. incorrect explanations of the same type, 8/10 chose the correct explanation when both were Hierarchical and 8/10 did so when both were Formula-driven, but only 4/10 did so when both were Intuitive. (This suggests a trend, but the difference is not statistically significant.)

For correct vs. incorrect comparisons of differing types, we found that in Hierarchical vs. Intuitive comparisons, 14/20 chose the Hierarchical explanation when it was correct but only 8/20 chose the Intuitive when *it* was correct (difference significant, with $t(9) = 2.71$, $p = .024$). But in Hierarchical vs. Formula-driven comparisons, nearly equal numbers (16/20 and 15/20) chose the correct explanation regardless of type.

In short, the Hierarchical explanations were most preferred, the Intuitive explanations least preferred. If the correct explanation was Intuitive, it was chosen less frequently than if the correct option or both options were of the two more recognizably "physics-like" types. It is noteworthy that of the three types, students found Intuitive explanations most difficult to judge correct or incorrect, even when comparing a correct and an incorrect explanation of the same type. This suggests that if students are to be able to apply physics knowledge to real-world problems, more bridging is needed between everyday phenomena and ordinary language representations on the one hand, and formal physics concepts and mathematics on the other. Although some efforts (e.g., Reif, 1984) have been made in this direction, the linkages forged in most introductory physics courses are inadequate.

GENERAL DISCUSSION AND INSTRUCTIONAL IMPLICATIONS

The Generation Experiment shows that students' explanations provide roughly the same sorting of students for assessment purposes as do problem solving tasks (Touger *et al.*, in press), but they provide richer insights into the ways that students do and do not think about physics situations. Those insights must be tempered by caution in the way *we* interpret students' words as an indication of what they are thinking. The students who had in mind a step-function change in velocity when they described a block as "slow[ing] down even more" on a rougher surface serve as a reminder that novices can use the same words as experts but mean something entirely different. Nevertheless, the task reveals that a range of connections -- among physics knowledge, real world knowledge, and the words that might encode or evoke that knowledge -- have not sufficiently been established in the knowledge stores of students whose grades indicated they had "successfully" completed a semester of introductory mechanics.

In fact, the words may remain a somewhat separate domain from either formal physics knowledge or real world knowledge to the extent that they remain place-holders for knowledge not yet firmly established. This may be the case where the student's physics knowledge is inedequate to distinguish between different physics terms. For example, in the Explanations Experiment we found that students describing the collision between the block and the spring tended to use the word "impact", which has no formal physics meaning, rather than physics terms like force or impulse, for which they might not yet have clearly separable real world associations.

Why not? In their physics course, they learn about the concept of force, which is typically linked at the introductory level to the notion of "a push or a pull". Later in the course, they learn that the *impulse* in a collision is $F\Delta t = m\Delta v$. Students in several high school classes (Haber-Schaim, Tripp, and Touger, unpublished) were generally able to identify the correct equation for the impulse of a bat on a ball in a multiple choice task. On the next question, a significant number of those students chose the same expression for the *force* the bat exerts on the ball. For these students the two concepts were not sufficiently distinguishable, describing separable aspects of real world behavior. To a physicist, force is an instantaneous quantity; an impulse, in contrast, has a duration Δt . "A push or a pull", as the student typically envisions it in real world contexts, also has duration. But they have been taught that that is a force. This may well reinforce any confusion they are experiencing.

The Judgment Experiment indicates that many students have inadequately reconciled the world of physics with the world of ordinary experience, preferring (and being better able to judge the correctness of) explanations (Hierarchical) in the accustomed language of formal physics to explanations couched in everyday terms. For such students, the boundaries of physics-world thinking and of real-world thinking are not at all coextensive. This can lead to the type of reasoning -- exemplified by the students in the Generation Experiment who assumed that a block sliding onto a rough surface slowed down but did not stop -- in which physics conclusions are unmonitored by expectations derived from real world experience.[2] As we help students to recognize the range of applicability of the concepts that they learn, we must find ways of assuring that they also recognize that the conceptual world that is taking shape is congruent to, and must be cross-referenced with, the world of experience.

Comparing results of the Generation and Judgment Experiments, we find that students are less able to produce Hierarchical explanations as output but prefer them as input, perhaps as a consequence of formal instruction. In contrast, they produce Intuitive explanations more frequently, but do not prefer them as input, suggesting that students may well be writing them as a default strategy. (Formula-driven explanations are written as output and selected as input with comparable frequency.)

We speculate that those students who write Intuitive explanations yet judge Hierarchical explanations to be superior are unable to write Hierarchical explanations because their knowledge store is poorly developed, poorly organized, or both. Emerging evidence would suggest that we might be able to help these students further develop and organize their knowledge store by having them practice writing qualitative explanations as part of regular instruction. In these writing activities, the students should be specifically encouraged to think about the connections among words, symbols, physics concepts, and the real-world behaviors they purport to represent.

Preliminary findings from an experiment in which students enrolled in a calculus-based mechanics course were taught to write qualitative strategies for problems in homework and exams indicate that, at the end of the course, these students were better able to identify the major concept(s) that apply to problems than similar students from a course in which they were not taught to write qualitative strategies (Dufresne, Gerace, Leonard, & Mestre, 1992). These, and related findings from other studies on the nature of acquisition of expertise (Dufresne, Gerace, Hardiman, & Mestre, 1992; Sweller, 1988; Sweller & Cooper, 1985), suggest that simply having novices practice solving lots of problems, as is the tradition in physics instruction, is not an efficient means either for helping individuals organize their knowledge or for strengthening connections between physics knowledge and real-world knowledge.

FOOTNOTES

1 In addition to our subjects, five experts did the Generation task. These were Ph.D. physicists with considerable recent experience teaching elementary mechanics. As we expected, their explanations tended to be Hierarchical.

2 The lack of connection between "real-world" experiences and experiences within the mathematics classroom has also been observed in the mathematics component of the third National Assessment of Educational Progress. In the problem, "An army bus holds 36 soldiers. If 1,128 soldiers are being bussed to

their training site, how many buses are needed," over 40% of all thirteen-year-olds tested (both with and without calculators) gave answers of either 31 or $31\frac{1}{3}$ buses. (See Lindquist, Carpenter, Silver, & Matthews, 1983)

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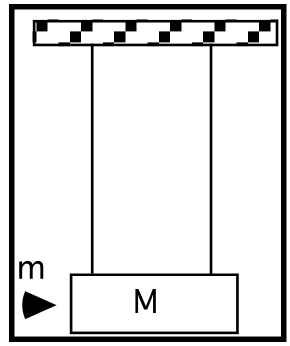
APPENDIX

Examples of Formula-driven, Hierarchical, and Intuitive explanations used in the Judgment Experiment for the following question :



A block of mass M, initially at rest , is suspended by long ropes from a ceiling, as shown. A bullet of mass m, traveling horizontally, enters the block and lodges in it.

Explain how shortening the length of the ropes will affect the motion of the block once the bullet is lodged in it. (Assume the ropes are still long enough so that there is no chance of the block hitting the ceiling.)

Formula-driven (correct)

$$mv_o = mv + MV$$

But $v = V$, so $mv_o = (m + M)v$

or $v = \frac{mv_o}{m + M}$.

Also, $\frac{1}{2}(m + M)\, v^2 = (m + M)gh$

so $\frac{1}{2}(m + M)\left(\frac{mv_o}{m + M}\right)^2 = (m + M)gh$,

or $\frac{1}{2g}\left(\frac{mv_o}{m + M}\right)^2 = h.$

Since v_o, g , m , and M are all the same as in the first situation, the block rises to the same height h .

APPENDIX (Cont'd)

Hierarchical (incorrect)

We assume the distance traveled by the block while the bullet is penetrating it is negligible. With that assumption, momentum is conserved during the collision. Since the bullet starts out with the same initial momentum each time, the momentum of the block-bullet system immediately after collision is also the same in each case.

Thus the block-bullet system also has the same kinetic energy immediately after the collision. The work-energy theorem applies to what happens subsequently. It takes the same amount of work to reduce the kinetic energy to zero each time, so the force must be exerted over the same distance. But when the ropes are shortened, the system travels in a circle of smaller radius, so to go the same distance it must rise higher.

Intuitive (correct)

In the second case, the block will be moving just as fast immediately after the bullet has lodged in it, assuming the block has moved too little for the ropes to have had much effect. In both cases, also, the block follows a circular (constant radius) path because the ropes don't get any longer.

The ropes are therefore always perpendicular to the block's motion. In other words, none of their pull is opposite to the block's motion, so they have no effect on slowing the block down. Only gravity does that. Since gravity pulls straight down, it only affects the upward part of the block's motion, just as it does in the first case. Thus the block rises just as high before being slowed to a stop and starting to swing back.

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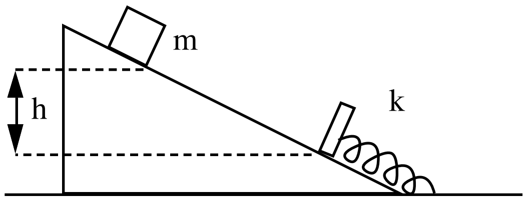
Figure 1

The Explanation Task Questions.

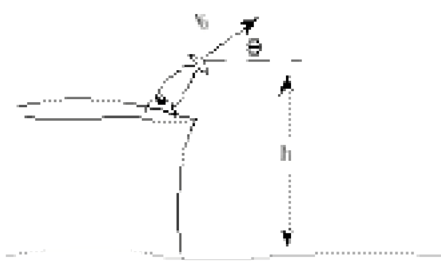
SET A

Situation: A block of mass *m*, initially at rest, slides down a frictionless ramp from a vertical height *h* onto a light spring of force constant *k*.



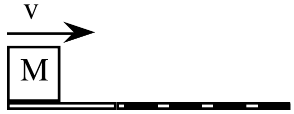
A1. Explain any changes in the behavior of this set-up when the block is released from a vertical height of .5*h* rather than *h*.

Situation: A cannon sitting on a cliff of height *h* fires a cannonball of mass *m* with a muzzle speed v_O at an angle θ above the horizontal.



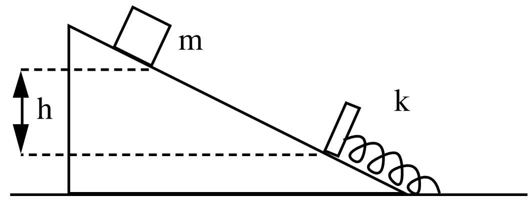
A2. Explain as precisely as you can how increasing the angle θ will affect the subsequent motion of the cannonball.

Situation: A block of mass M slides across a smooth floor at velocity v, then enters a rough region.



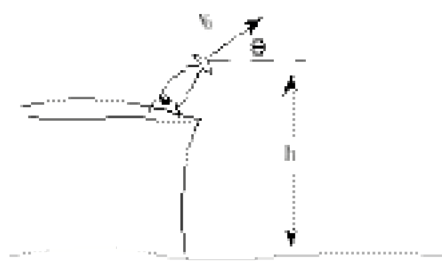
SET B

Situation: A block of mass *m*, initially at rest, slides down a frictionless ramp from a vertical height *h* onto a light spring of force constant *k*.



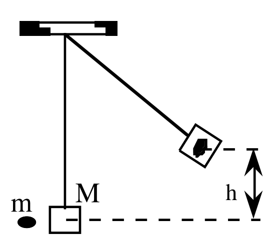
B2. Explain any changes in the behavior of this set-up if it takes place on the moon rather than on earth.

Situation: A cannon sitting on a cliff of height *h* fires a cannonball of mass *m* with a muzzle speed v_O at an angle θ above the horizontal.



B1. Explain as precisely as you can how increasing the height from *h* to *2h* will affect the subsequent motion of the cannonball.

Situation: A bullet of mass m strikes and embeds itself in a block of mass M hanging from a string.



A3. Explain how increasing the coefficient of friction affects the motion of the block in the rough region.

B3. Explain any changes in the behavior of the system if it takes place on the moon rather than on earth.

Table 1

Pattern of Administration for the Judgment Experiment
Two Latin squares, each done twice.

	HC/XC	**HC/HI**	**HC/XI**	**XC/XI**	**XC/HI**
Q1	S1	S2	S3	S4	S5
Q2	S5	S1	S2	S3	S4
Q3	S4	S5	S1	S2	S3
Q4	S3	S4	S5	S1	S2
Q5	S2	S3	S4	S5	S1

KEY

First Letter
H = Hierarchical
X = Formula-driven (Latin Square 1)
Intuitive (Latin Square 2)
Q = Question
S = Subject

Second Letter
C = Correct
I = Incorrect

Total number of subjects: 20

Table 2

Results of Judgment Experiment: The number of students choosing the first/second explanation in each comparison pair

Comparison Pairings				
HC IC	**HC HI**	**HC II**	**IC II**	**IC HI**
10 0	**7 3**	**7 3**	**4 6**	**4 6**
HC FC	**HC HI**	**HC FI**	**FC FI**	**FC HI**
7 3	**8 2**	**8 2**	**8 2**	**7 3**

KEY

First Letter
H = Hierarchical
F = Formula-driven
I = Intuitive

Second Letter
C = Correct
I = Incorrect