Exams as a Learning Experience for Students and Teachers*

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ABSTRACT FOR AAPT 1994 SUMMER MEETING (NOTRE DAME)

A common view of assessment is that exams should measure the current state of students' knowledge. Consequently, many test questions rely heavily on memory and on the ability to recognize and translate from analogous questions. Research indicates that traditional assessments do not reveal the extent of students' understanding. Our view is that exams can measure understanding (rather than recall or manipulative skills), and that exams can be rich, educational experiences for both students and teachers. We will present and explain the value of a style of question called "extended context", which is useful both for gauging students' understanding and for helping them to learn. A second style, which we call "compare and contrast with explanation", is relatively simple to apply, yet is excellent for revealing what students are focused on and for exhibiting the reasoning students use while problem solving. Examples will be provided, along with student-generated responses.

Introduction: We all want to measure "understanding" as well as problem-solving proficiency, critical thinking ability, and knowledge of basic definitions, equations, and results. Many of us would like to do this within a problem-solving context. Unfortunately, it's very difficult to create problems that are good assessments. We can all recognize a good problem when we see one. Some people seem to have a knack for making up great problems. The rest of us are stuck wondering how we can make up our own good problems. One general way to do this ourselves is by using "extended context", which simply means taking students into unfamiliar territory. In this way, we can more thoroughly and confidently assess students' states of mind. Furthermore, students actually "learn" while taking the exam, because they often must reorganize knowledge, make connections, and see relationships between ideas during the process rather than beforehand while studying. Thus, exams are truly a "learning experience" for both students and teachers.

Two general types will be discussed. The first involves conventional problem-solving problems altered using "extended context". The second also involves extended context, but the style is very different from conventional problems. We call it "compare and contrast with explanation" in which two physical quantities or situations are put side-by-side. Students are asked to compare the two and give their reasoning.

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Goals and Purposes of Exams: There are many different reasons to give exams. Listed below are some of the "traditional" reasons, as well as some of our own. The "traditional" goals are still valid, but we believe we can take them one step farther.

WHY DO WE GIVE EXAMS?	BUT WHY NOT ALSO?
to measure current state of students' knowledge	to re-organize students' knowledge structure
to assess problem-solving skills	to impact problem-solving; to develop "concept-based" problem-solving skills
to test critical thinking ability	to enhance critical thinking
to motivate students to ... memorize formulas, etc.	to motivate students to determine how they learn best
to determine how much students understand	to help students understand concepts and relationships better

TABLE I. VARIOUS GOALS AND PURPOSES OF "TRADITIONAL" EXAMS AS WELL AS OUR OWN.

What IS "Extended Context"? "Extended Context" means simply to go beyond the ordinary and familiar, so that students and teachers can explore the boundaries of understanding. The idea can be applied to any part of teaching and learning. We have simply applied it to exams.

General Features of Extended Context: All extended-context problems share some general features. They are:

- Problems are relatively difficult for students, primarily because they don't have much experience with this sort of exam. However, students quickly learn how to adapt and prepare.
- The physical situation is relatively simple for the students to grasp. These problems are not hard because they are complicated. Students generally know fairly quickly what the situation is and what is being asked. The hard part for them is trying to apply concepts and principles to the situation.
- Memorized or previously derived equations are usually not useful. Sometimes, this is because the problem does not require equations to find the answer.

Other times, it is because a new set of equations must be derived for the situation.

- Even though conceptual understanding is probed and impacted, the questions are not overtly conceptual. The form is similar to a conventional exam (superficially) in that problems and problem-solving situations are being used throughout. The difference is the structure of the problems and questions begin asked.

- Although the problems are somewhat traditional, we often ask students to explain their answers or write out how they would solve a particular problem. We have found that much more of students' thought processes are revealed this way.

Five Ways to "Extend the Context": The first four types are ways to use extend context with tradition-style problems. The fifth type is a new way to probe and impact students' problem-solving approaches and conceptual understanding.

(1) Use the same old situation, but ask a different question. The simplest way to extend the context of a problem is to use a familiar situation, but to ask an unusual question. For instance, in Figure 1(a), we have a traditional combination of blocks on strings over pulleys. However, instead of giving students the two masses and the angle of the incline (which is probably a problem they've done many times), we have given them only one of the masses and its acceleration. This question is particularly easy for someone who is thinking about basic concepts and principles, and hard for someone who isn't. One major drawback of this type of problem is that a student who is very procedural will "stumble" onto the answer, perhaps without understanding the concepts very well. This is because the problem "looks" like a traditional problem with a traditional solution. Two more examples of this type of problem are shown in Figures 1(b) and (c).

(2) Ask the same old question, but use a new situation. As stated earlier, the new situation should be unfamiliar but still immediately recognizable to students. It's often best to try to anticipate student tendencies to generalize incorrectly or poorly. For example, in Figure 2(a), a woman is "stuck" to the wall of this amusement park ride. Because students often believe that friction points opposite to the direction of motion, they will be confused by this situation. Students who understand that static friction is a constraint force (and who understand what that means) will succeed. Two more examples are shown in Figures 2(b) and (c).

Five Ways to "Extend the Context": (continued)

(3) Combine simple ideas/situations. This type is very good for integrating topics taught at different times of the year. The simplest way to do this is to ask a conventional question for a conventional situation, but give information in a way that requires using knowledge from much earlier in the course. For instance, in a standard "F=ma" problem, give the acceleration indirectly so that kinematics must be used. Most examples are in fact much richer than this, as shown in Figure 3. Parts (a) and (b) are traditional and straightforward, but the rest of the problem combines circular motion/kinematics with straight-line motion/kinematics and impulse/momentum. As before, no memorized equations will answer these questions for you, but knowledge of basic principles and how to apply them to new situations will!

(4) Use an unfamiliar representation. Sometimes we can give information in a way that is not immediately recognized by students. They haven't yet been taught how to interpret it. They must learn how to do so *during the exam*! Making sense of a new representation requires conceptual analysis and can help students build connections between ideas not previously made. In Figure 4(a), four diffraction patterns are shown. However the patterns are somewhat stylized, and students must examine the pattern to decide what it is telling them. Answers on this type of question are more likely to reveal lingering misunderstandings rather than confusion or frustration with the unfamiliar representation. A second example is shown in Figure 4(b).

(5) Compare two or more situations. This type often indirectly combines types 2, 3 and 4. The emphasis however is on the simultaneous consideration of multiple situations. Sometimes we create as many as 10 situations and ask a variety of questions. An example is shown in Figure 5. Although all previous examples were taken from introductory physics courses, extended context can be used at all levels. This problem was taken from the final exam of a graduate-level quantum mechanics course.

Another way to implement this type is to consider exactly two objects or situations and ask students to compare some physical quantity. We now examine this style in greater detail.

Compare and Contrast with Explanation: Consider the example in Figure 6(a). In cases like this students could actually use equations to solve the problem, but their tendency is to "leap" to an answer. When asked to explain their answer, we often find out what they are focusing on. Samples of student responses are shown in Figure 6(b).

Examples of Students' Explanations: There are only 4 possible responses to this question: (1) The sphere lands farther than the block; (2) it lands at the same position; (3) it lands closer than the block; and (4) there's not enough information. Students' explanations can vary quite a bit. Here are some of the typical responses:

"The sphere will land closer because the block's potential energy at the top got turned into linear kinetic energy by the time it got to the jump. The sphere, however, used some of its energy to rotate. Therefore, it didn't have the velocity of the block, nor the distance L."

"They land in the same place because they both experience the same force. Just because one rolls does not mean its center of mass has more linear speed."

"The sphere will land in the same place as the block since the force of gravity is the only force, and since gravity acts on an object as if its mass were just its cm then both cm's will have the same trajectory."

"Further since it has gained angular momentum."

"The sphere will go farther than the block. Because it rolls without slipping on the track, frictional forces do not slow it down and it has a greater horizontal speed when it starts to fall."

Analysis of Students' Explanations: Looking at all the students' explanations in Figure 6(b), we can see that there are lots of different types of "wrong" answers. For example, we see some interesting ideas about friction and also about energy. The explanations accompanying the correct answers are very good. Notice that none of the explanations are particularly long, so this type of exam question doesn't necessarily take a long time for students to do. In general, we believe that this type of question is very good for seeing what students are paying attention to while analyzing problem situations.

Advice to Students: How do students prepare for this type of exam, and what advice do we give them beforehand? The only real preparation is keeping up with all the material and assignments, and reflecting on the learning process. Students' tendency (especially among first-year students) is to stay up all night the night before an exam and "cram". The first test of the year is usually a minor disaster, but afterwards, students know what to pay attention to. We usually tell students to get a good night's sleep and do as *little* physics as possible on the day of the exam. Few students take our advice (the first time!) but wish they had.

Students' Reaction: Students are uniformly positive toward this style of exam. They feel it's fair and that they should have been able to do the problems. They perceive the problems as "easy, if they knew what to do." They tend to be encouraged and perhaps even a bit proud that someone believes they can think rather than regurgitate. They often become much more aggressive learners afterwards.

Conclusions:

(1) Exams can have pedagogic value. Students can learn during an exam!

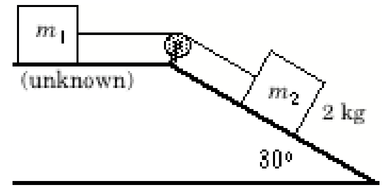
(2) Students can learn how to prepare for and take this type of exam.

(3) To assess understanding, we must take students into unfamiliar territory. "Extended Context" is the way to do so.

(4) Teachers also learn more with this type of exam. In this way, exams are a learning experience for both students and teachers.

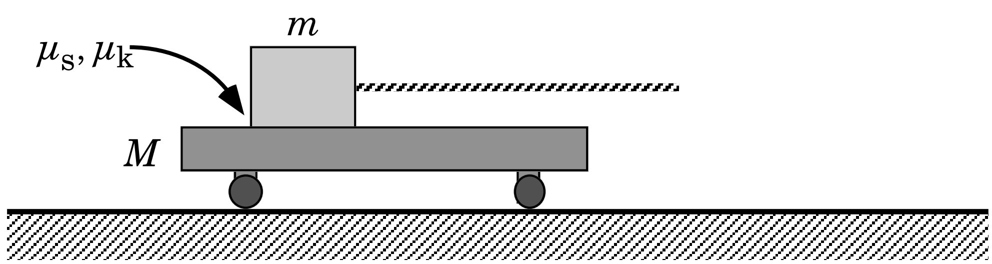
(5) Now all of us can make up our own "good" problems!

Two masses, m_1 and m_2 , are connected by a string that passes over a massless pulley. m_2 = 2 kg, and both masses have an acceleration a = 2.5 m/s^2. Determine the tension in the string. (Use g = 10 N/kg.)



(a)

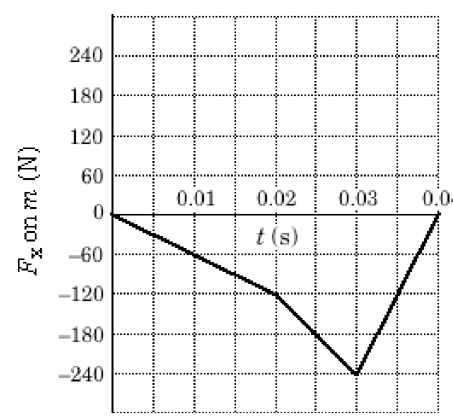
A flat cart of mass M can move on a horizontal surface without any friction. A block of mass m sits on the surface of the cart and is attached to a massless string as shown. The coefficient of static friction between the block and cart is μ_s, and the coefficient of kinetic friction between the block and the cart is μ_k. Explain how you would go about determining the value of the tension in the string that would cause the **cart** to have maximum acceleration.



(b)

A mass m = 0.5 kg travels on a horizontal frictionless surface with a momentum p = 2.5 kg-m/s directed in the positive x-direction. The mass collides with another mass M which is initially at rest. A graph of the force (as a function of time) acting on m during the collision is shown to the right.

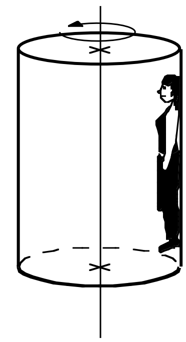
How much work was done on m during the collision?



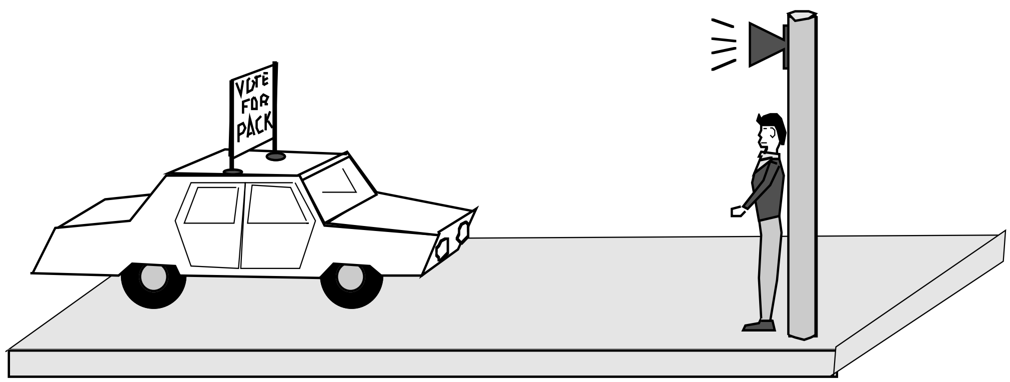
(c)

FIGURE 1. THREE EXAMPLES OF USING A FAMILIAR SITUATION BUT ASKING AN UNFAMILIAR QUESTION.

An amusement park ride consists of a large vertical cylinder, 5 m in radius, that spins about its axis fast enough that any person inside can remain fixed against the wall (see figure). Take the mass of the woman to be 50 kg, the speed of a point on the wall to be 15 m/s, and the coefficient of static friction between the woman and the wall to be 0.4. Find the frictional force that the wall exerts on the woman.



(a)

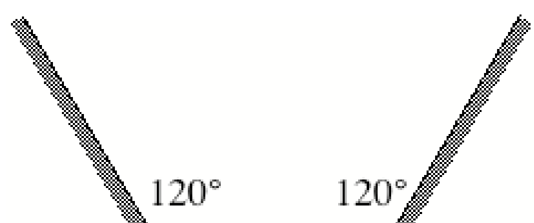


A sound source is emitting a wave having a frequency of 400 Hz. A campaign car (a car carrying a large political advertisement on its roof) is directly approaching the sound source with a speed of 25 m/s. What frequency does the driver of the car hear?

The original sound wave is reflected from the sign on the car and is heard by someone standing near the source. What is the frequency of the reflected wave as heard by the observer near the source?

(b)

Consider an arrangement of three plane mirrors as shown. (Such devices are typically seen in clothing stores.) There are locations in the region between the mirrors where someone would see only a single image of themselves. There are other regions where two images could be seen, and still other regions where more than two images could be seen. Indicate on the diagram*, or a carefully drawn copy, each of these regions and ***explain*** your method for defining each region. What is the maximum number of images that can be seen. (Remember that for this part you are the observer as well as the object. Also, the back of all pages have triangular graph paper printed. Be sure to clearly indicate where your final response is located.)

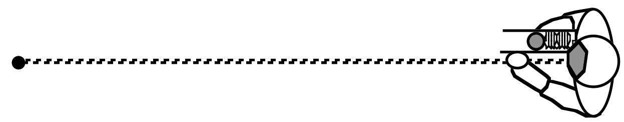


(c)

*On the actual exam, students were given a grid of equilateral triangles.

FIGURE 2. THREE EXAMPLES OF USING AN UNFAMILIAR SITUATION.

An astronaut (mass m_A) in space, tied to the end of a tether of length 10 m, is traveling in a circle with constant speed making one revolution every 15 seconds.

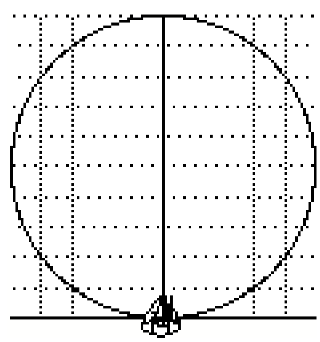


(a) What is the speed of the astronaut?

(b) What is the tension in the tether?

At a certain time the astronaut points a spring-loaded gun towards the center of the circle and fires a small ball.

(c) Assume that the astronaut fires the spring-loaded gun when at the origin. On the diagram provided, sketch the trajectory of the ball.

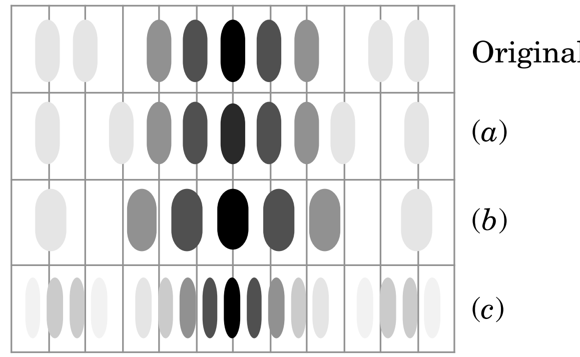


(d) If the gun is directed toward the center of the circle, then regardless of the speed of the ball the astronaut can not catch the ball. Explain why this is so.

(e) Is there any circumstance for which the astronaut can fire the gun and catch the ball? Explain.

FIGURE 3. AN EXAMPLE OF COMBINING SIMPLE IDEAS INTO ONE SITUATION.

The top of the figure at right shows the diffraction pattern resulting from two slits of width a separated by a distance d when illuminated by a plane wave of light having wavelength λ and intensity I. Each of the other patterns are formed when exactly ***one*** of the parameters (a, d, λ, or I) is changed. For each figure identify the parameter that was changed and describe the features of the diffraction pattern that you used to identify the changed parameter.



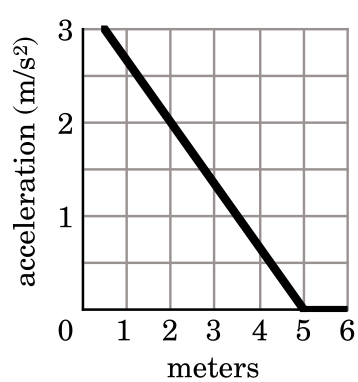
(a) **Parameter changed: _______**
Explanation:

(b) **Parameter changed: _______**
Explanation:

(c) **Parameter changed: _______**
Explanation:

(a)

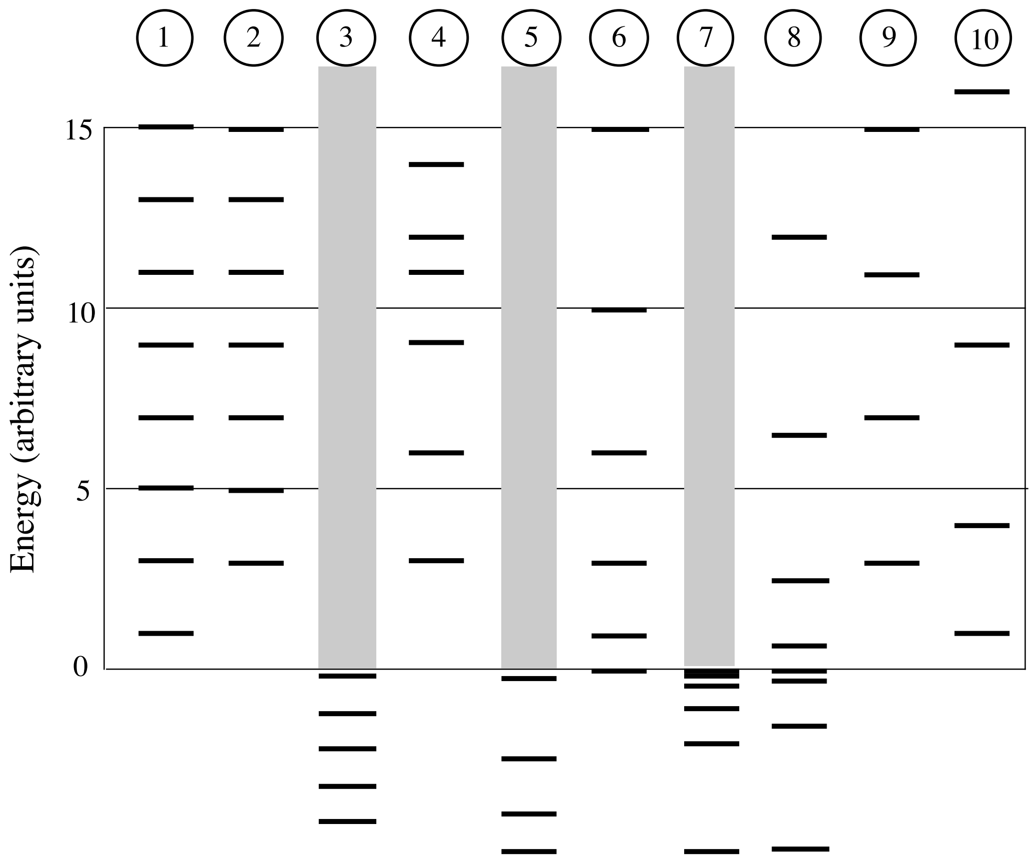
A mass $m = 0.5$ kg is released from rest at the position $x = 2$ m and travels to the position $x = 5$ m while accelerated according to the plot shown at the right. What is the speed of the mass when it reaches the position $x = 5$ m?



(b)

FIGURE 4. TWO EXAMPLES OF GIVING INFORMATION IN AN UNFAMILIAR REPRESENTATION.

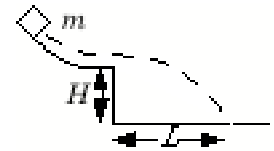
Consider the following energy level diagrams (spectra). Within each individual spectrum, the spacings between levels is relatively correct. However, each spectrum has been scaled by some overall factor, so the actual energy has no significance. Using the patterns of the eigenvalues, determine which of the spectra should be associated with one of the following Hamiltonians. In each case, give the degeneracy of the 1st <u>excited</u> state.



SPECTRUM	DEGENERACY OF 1ST EXCITED STATE	HAMILTONIAN
a) ______	______	One-dimensional square well (particle in a box).
b) ______	______	One-dimensional harmonic oscillator.
c) ______	______	Coulomb potential.
d) ______	______	Three-dimensional harmonic oscillator.
e) ______	______	One-dimensional finite square well.
f) ______	______	Three-dimensional square well (particle in a cube).
g) ______	______	Rigid rotor ($H = L^2/2I$).
h) ______	______	Half-harmonic oscillator ($V={}^1/_2kx^2$ for $x>0$; $V=\infty$ for $x<0$).

FIGURE 5. AN EXAMPLE OF EXPLORING MULTIPLE SITUATIONS.

A block of mass m is released from rest from the top of the circular track shown at right and allowed to fall a distance H from the bottom of the track. The block is frictionless. The mass lands a distance L from a point directly below the end of the track. A sphere of radius R and identical mass m is also released from rest and rolls without slipping down the same track. After falling the distance H, does the sphere land closer, further, or the same distance from the track than the block?



(a)

"The sphere will land closer because the block's potential energy at the top got turned into linear kinetic energy by the time it got to the jump. The sphere, however, used some of its energy to rotate. Therefore, it didn't have the velocity of the block, nor the distance L."

"The velocity at the point H determines its distance L. While the sphere rotates, using up some of its energy to do so, the block does not. It uses all its energy to move and will have a larger L."

"The sphere lands closer because the sphere has a rotational speed and the block doesn't. Therefore the block has a greater linear velocity before it flies off and travels a greater distance."

"Since both objects are frictionless, both should land at the same point."

"Same. The c.m. of the sphere has the same energy as the block."

"One is frictionless and the other is rolling without slipping; both will have equal velocities; equal mass; sphere lands same distance. Prove it using Work Energy."

"They land in the same place because they both experience the same force. Just because one rolls does not mean its center of mass has more linear speed."

"Same distance, but only because there is no friction between block and track. If there were, then sphere would go farther because friction wouldn't affect it, because it's rolling without slipping."

"The sphere will land in the same place as the block since the force of gravity is the only force, and since gravity acts on an object as if its mass were just its cm then both cm's will have the same trajectory."

"Further since it has gained angular momentum."

"It depends which object has a greater velocity just before leaving the track. This would be the sphere, because it had more energy; it had to translate and rotate."

"The sphere would land farther than the block because the sphere would accelerate more than the block. Also, the sphere would have less air resistance than the block as it traveled through the air."

"The sphere lands further because it has an angular acceleration."

"The sphere will go farther than the block. Because it rolls without slipping on the track, frictional forces do not slow it down and it has a greater horizontal speed when it starts to fall."

"The sphere will go further 'cos it has more energy."

(b)

FIGURE 6. AN EXAMPLE OF "COMPARE AND CONTRAST WITH EXPLANATION" (a) THE PROBLEM; (b) SAMPLE STUDENT RESPONSES.