
Physics Exam Problems Reconsidered: *Using Logger Pro to Evaluate Student Understanding of Physics*

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In the past few decades, the physics teaching community has witnessed a surge in creative and often effective ways of using technology to improve physics instruction.¹⁻³ Most of these findings suggest how technology can help instructors create interactive learning environments and how interactivity influences the effectiveness of physics learning.⁴ However, every physics teacher knows that in order for any teaching method to be effective, the exams have to test the skills and concepts addressed by the teacher. Exam content and style sends the clearest message to students about what skills and content are valued by instructors. The mismatch between what we intend to teach and what we effectively test in exams is of great concern to many science teachers. These were our motives for creating data-rich questions to be used in the exams in a large undergraduate first-year physics course at the University of British Columbia. These data-rich questions were developed to support the use of an innovative teaching pedagogy called Interactive Lecture Experiments.³

Interactive Lecture Experiments

Interactive Lecture Experiments described here have been implemented in a large (700 students) first-year algebra-based introductory physics course (Physics 100)^{3,5} for science majors at the University of British Columbia. The course is split into three sections of about 230 students, with three instructors, including one of the authors (MMB). This teaching method builds on Sokoloff and Thornton's¹ Interac-

tive Lecture Demonstrations. Every Interactive Lecture Experiment had a similar format: the students observe an experiment during a lecture; the data from the experiment were recorded using either Logger Pro sensors or video cameras (Vernier Technology);⁶ then the data were uploaded on the web as a Logger Pro file to be analyzed by the students at home. In the next lecture, students were asked to bring their results to class for discussion and assessment.

Logger Pro Technology allows the course instructor to collect experimental data using electronic probes (for example, motion detectors for recording an object's displacement at various times) and displays this data in a spreadsheet and/or graph form when paired with the Logger Pro software. Thanks to Vernier Software & Technology, each student has a copy of Logger Pro software and can analyze the data outside of class while working in small groups or alone. It is important to mention that traditionally Logger Pro or similar technology is used in labs or during small group collaborative problem solving sessions where every group of students has access to it and can conduct experiments independently.⁷⁻¹⁰ In the study described here, Logger Pro was used during the labs as well as during the large lectures.

In the current paper, the latter pedagogy is referred to as Interactive Lecture Experiments (ILEs). During the fall semester of 2006, we implemented six ILEs in each one of three sections of the large Physics 100 course⁵ (See Table I). An example of an ILE is shown in Fig. 1. In this experiment a ball is rolled off the horizontal table and bounced off the floor. The students

were asked to analyze the motion of the ball during its fall off the table as well as during and after the bounce. This simple experiment can be used to illustrate many topics including projectile motion, free fall, conservation of linear momentum, and energy during elastic and inelastic collisions.

One of the advantages of using Logger Pro is that a student does not need calculus in order to find the area under the graph or its slope. The software provides built-in functions to find the area under the curve and its slope. This becomes especially helpful when teaching algebra-based physics courses (see Fig. 2).

Using Logger Pro Technology to Test Student Conceptual Understanding

Interactive Lecture Experiments with data collection and analysis using Logger Pro Technology were a regular part of the physics lecture and laboratory instruction. Active student participation during the lecture was encouraged by awarding participation marks when students answered questions about the ILEs using Peer Response System technology (clickers), and the accuracy of their responses was not graded. Yet the main reason most of the students took these experiments seriously was that they knew that similar analysis would be part of their exams. Exams included a theory exam conducted during the lecture and a hands-on lab exam conducted at the end of the term. Since a theory exam was administered in a large lecture hall, there was no opportunity to use hands-on data analysis during the exam. To resolve this issue, we decided to formulate multiple-choice questions, which required the students to interpret previously collected data. Below we provide a few examples of the types of questions employed in the theoretical part of the final exams to test student conceptual understanding.

Two Multiple-Choice Questions: Analyzing Projectile Motion

1. Your friend analyzed a video clip of a basketball shot using a Logger Pro Video Analysis feature. However, she was not certain how to find the acceleration of free fall from her analysis and turned to you for advice. What is the **reasonable experimental value** of the **magnitude** of the acceleration of free fall your friend should report

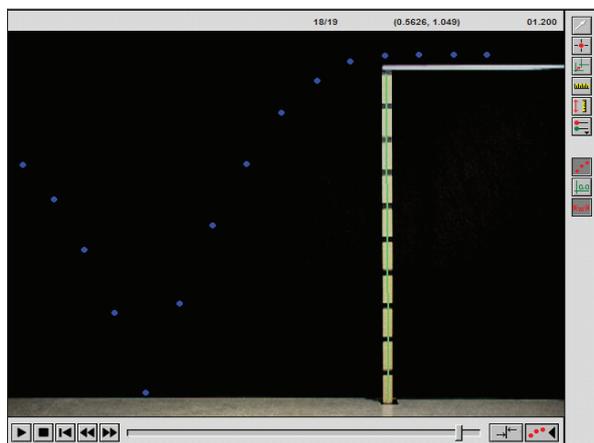


Fig. 1. A video clip and a video analysis of a ball rolling off the table and bouncing off the floor. To make the video analysis possible, a meter stick was placed vertically and 10-cm intervals on the meter stick were indicated by the black tape.



Fig. 2. Built-in functions displayed on the Logger Pro menu provide students with simple ways to examine and analyze graphical data. For example: finding slope, area under the graph, the best fit line, statistical information, or examining the graph point by point.

ILE	Description of ILE	Topic
ILE 1	ball thrown up in the air	1-D Kinematics
ILE 2	ball rolling off a table	2-D Kinematics
ILE 3	a block sliding off an accelerating cart	Newton's laws, static and kinetic friction
ILE 4	Jumping Kelly: force vs time data plotted as a student jumps on a scale	apparent weight, normal force
ILE 5	when pigs fly: position vs time data plotted as a pig flies in a circle	conical pendulum, circular motion
ILE 6	pendulum	pendulum, tension, circular motion

Table 1. List of interactive lecture experiments and topics they addressed.

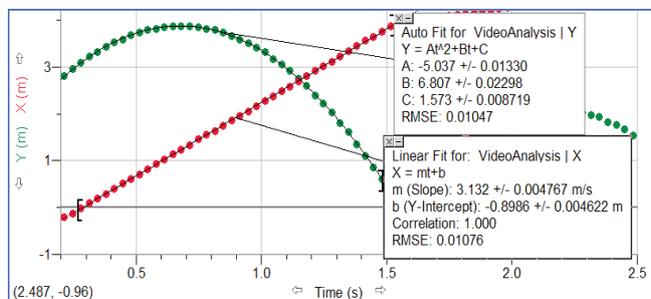


Fig. 3. Results of the Video Analysis of a basketball shot.

during the next class?

- a) 5.037 m/s^2
- b) 6.807 m/s^2
- c) 9.823 m/s^2
- d) 10.074 m/s^2
- e) 10.10 m/s^2

Notice, that since this was the theoretical part of the exam, the data analysis had already been done for the students. However, the students had to decide how to interpret this information. The students were also asked to determine a reasonable accuracy that the result should be reported with. (The correct answer is **e**.) This question could have been improved by providing one more choice that is given with the correct accuracy but has a wrong physical meaning (for example, 13.6 m/s^2). This way students would be discriminating not only accuracy but also physics concepts.

2. Find the magnitude of the initial velocity of the ball in the previous question taking into account that the ball was thrown when the time reading on the clock was zero ($t = 0 \text{ s}$).
 - a) 3.13 m/s
 - b) 5.03 m/s
 - c) 6.81 m/s
 - d) 7.49 m/s
 - e) 9.94 m/s

To be able to answer this question correctly, the students have to understand how to extract the x and y components of the initial velocity and how to find the magnitude of a vector knowing its components. (The correct answer is **d**.)

Student Responses

The two questions mentioned above were used in the first midterm test for one section of Physics 100 ($N = 263$) about one month into the semester. By that time, every student had completed two Interactive Lecture Experiments and two laboratory sessions where Logger Pro software was also used for both data collection and analysis. The first lab served as an introduction to using Logger Pro for data collection and analysis while the second lab investigated one dimensional motion: falling object with and without air resistance. Logger Pro technology was used during all the laboratory sessions throughout the year (six in all), and the laboratory is worth 20% of the students' final grade in the course.

Analysis of Student Responses to the First Question

The distribution of student responses to the multiple-choice questions described above is shown in Table II. Twenty-three percent of students answered the first problem correctly. However, most of the incorrect responses were related to the fact that the students chose answer (**d**), which indicates that they understood the physics concept but did not realize that not all the digits provided by the software were meaningful. Considering response (**d**) to be partially correct, more than 80% of the students were able to solve this problem even though many of them did not know how to report their results properly. This data suggest that students pay more attention to applying physics concepts correctly than the data analysis skills, especially in a testing situation. It may also reveal that students place a great deal of trust in numbers generated from graphical analysis software and are reluctant to question or alter the result.

Analysis of Student Responses to the Second Question

This question appears to be more difficult (see Table II). It is not surprising, since for many students understanding of operations with vectors becomes a serious hurdle in physics problem solving.¹¹⁻¹³ Only 20% of the students were able to solve this problem correctly. The majority of the students used either x or y components of velocity as the representation of the magnitude of the entire velocity vector (speed).

Table II. Distributions of student responses to the multiple-choice questions.

Percentage of students with particular response and analysis of student mistakes ($N = 263$)				
Response	Question 1		Question 2	
A	9%	Students chose the correct coefficient but didn't incorporate a factor of 2.	17%	Used the x component of velocity rather than the entire vector magnitude to represent speed.
B	1%	Used the wrong coefficients (y component of initial velocity) from $y(t)$ graph to find acceleration.	3%	Used the wrong coefficient (half of acceleration) to represent speed.
C	9%	Used the "textbook value" not supported by experimental results.	60%	Used the y component of velocity rather than the entire vector magnitude to represent speed.
D	58%	Used correct procedure, got confused with significant digits (error analysis)	19%	Correct answer.
E	23%	Correct answer.	1%	Incorrect calculation of vector magnitude.

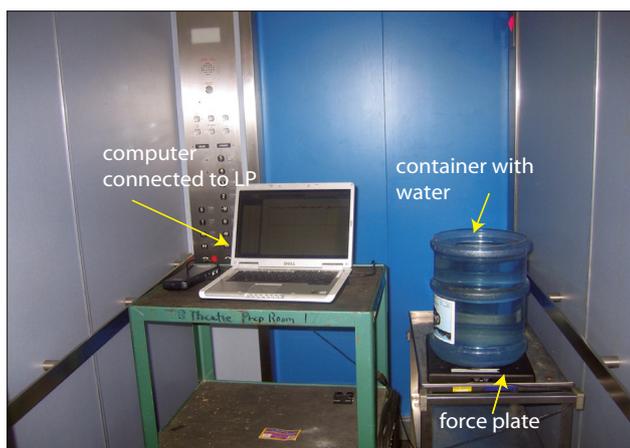


Fig. 4. Measuring apparent weight in a moving elevator.

This is a common problem among introductory physics students. In response to low results on exercises involving 2-D motion and resolving of vectors, a tutorial was designed and conducted that gave students extra practice in these types of problems in a variety of contexts. The use of Logger Pro software to plot both the x and y dependence should also help students to recognize that both need to be taken into account. On the final exam the same group of students fared much better on a 2-D conservation of momentum question (67% correct) showing marked improvement over the semester on this important skill.

Open Ended Problems: Two Examples

1. Finding acceleration of an elevator using a force plate and a jar of water

A student working in a physics demonstration room used a force plate (a digital scale) to record how the reading of a scale changed when a big container with water is put on it, and the whole system is placed in a moving elevator (Fig. 4). The data he collected are displayed below (Fig. 5) as a graph of the force (reading of a scale) as a function of time. Use these data to answer the following questions:

- Explain** what the readings of the scale show and estimate the mass and weight of the container with water. Clearly explain what you did and don't forget to draw a free body diagram.
- Indicate** three time intervals during which the elevator was accelerating. Determine if possible for these time intervals if the elevator was speeding up or slowing down and moving up or moving down.
- Estimate** the maximum acceleration of the elevator.

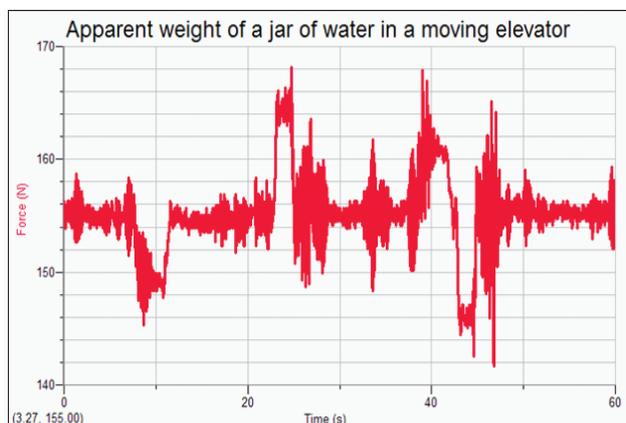


Fig. 5. Apparent weight of a jar of water in a moving elevator.

Analysis of student responses

Most of the students were able to solve this problem algebraically, estimating the elevator's maximum acceleration within a reasonable range ($0.5\text{--}1.5\text{ m/s}^2$). The students noticed that the weight of the water was about 155 N, which corresponds to the mass of the water to be about 15.8 kg and that the maximum discrepancy between the weight and the reading of the scale is about 13 N. This maximum discrepancy happens when the elevator has the maximum acceleration, which can be estimated using Newton's second law as the ratio of this discrepancy to the mass of the water (Eq. 1).

$$N - mg = ma$$

$$|a| = \frac{|N - mg|}{m} \approx \frac{13\text{ N}}{15.8\text{ kg}} = 0.8\text{ m/s}^2. \quad (1)$$

However, the students had significant difficulties matching the graphical representation of the normal force exerted on the water to the possible motion of the elevator (see Fig. 5). The most difficult part for the students was to realize that in order to decide whether the elevator was going up or down, they had to make some initial assumptions. For instance, one can assume that the elevator was initially at rest. Then the elevator started speeding up when moving downwards. During this time, the scale would read a force smaller than the actual weight of the water (8–11 s). Another possible scenario could have been that the elevator was moving up at a constant speed and then between 8 s and 11 s, it started slowing down before

stopping. In both cases, the acceleration of the elevator is directed downward, which effectively reduces the apparent weight of the water (scale reading). The majority of the students associate the direction of acceleration with the direction of an elevator's motion (velocity), which shows their lack of understanding of the concepts of velocity and acceleration. Nevertheless, even though this problem is relatively complex and also requires rather sophisticated data analysis, the average score was 61%, which is close to the average student performance on the first midterm test for this course (58% overall). Compared to the traditional problem of the apparent weight in an elevator, this problem asked the students to refer to the relevant data, come up with the possible scenario, and analyze it. This requires higher order thinking skills and helps students relate the physics they learn in class to everyday life and experimental situations.

2. Analyzing the bounce of a ball using Logger Pro Video Analysis

The picture below (Fig. 6) shows the video analysis of a 100-g ball rolling off a table. The same video clip was used in Fig. 1. The results of a sample analysis are shown below. Using the data, estimate the change of momentum of the ball during the collision with the floor.

Analysis of Student Responses

This problem demonstrates an example where the students were required to answer new questions about a familiar situation. The video clip, a snapshot of which is shown in Fig. 6, has been considered before in the context of projectile motion. However, during the exam the students were asked to estimate the change of momentum of the ball during its collision with the floor. The graphs of the horizontal and vertical components of velocity as functions of time were displayed as well. This question proved to be very difficult for the majority of the students, and the average score was only 41%. The main problem was that the students did not understand how to find the values of velocity before and after the collision from the graph and how to use this information to calculate the change of momentum. The fact that one of the digital frames of the video clip caught the ball when it touched the floor and instantaneously stopped

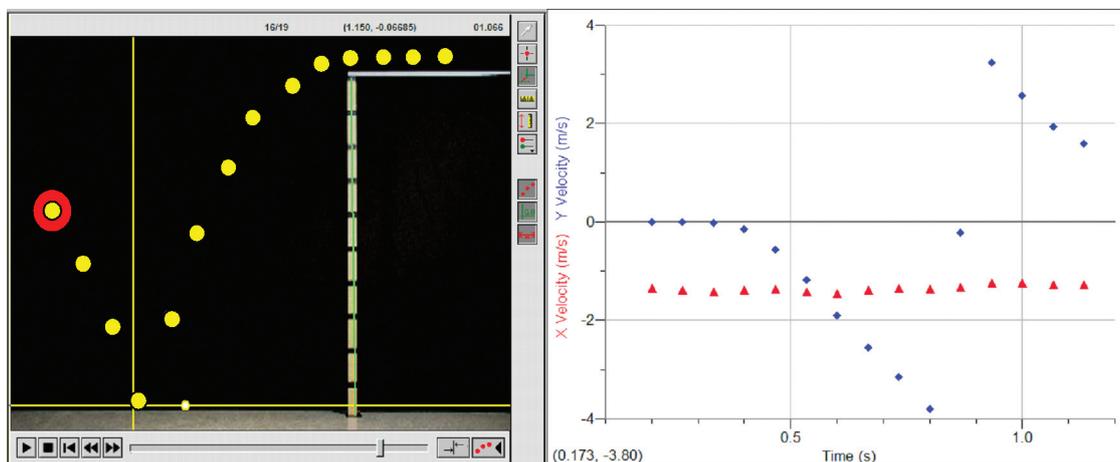


Fig. 6. Analyzing the bounce of a ball.

moving made it even harder. If we compare student responses to this real-life problem with their responses to a question asked during the lecture (Fig. 7), we can understand why solving a real-life problem becomes a challenge. In the lecture, 94% of students correctly answered the traditional physics problem, which is significantly lower than student performance on a data-rich question on the same topic. The real-life problem required the students to extract necessary information and figure out how to use it to solve a problem. On the other hand, in a traditional textbook-type problem, all the necessary information is provided, and the only challenge is to identify the right formula that will help a student to solve it.

Conclusions

This paper suggests a few examples of how modern technology can help physics teachers create exams that test higher order thinking skills such as data analysis

and evaluation by applying concepts learned in class to real-life situations. Logger Pro software provides a convenient tool for creating these kinds of exam problems. Our experience with using these questions in introductory physics exams indicates that although students are introduced to and given many opportunities to work with data and data analysis tools during lectures and labs, they are not necessarily well prepared for encountering these kinds of questions on exams. Yet we believe these kinds of questions have an important role to play in the assessment of our students. If data analysis and interpretation skills are being promoted in laboratory activities and assignments such as Interactive Lecture Experiments, then asking similar questions on exams reinforces the message that we are trying to send to the students. Physics instructors have to be clear about what kind of science skills they value and what problems the students should be able to solve as they complete their first-year physics course or even their science degree. If technology and data analysis techniques using software are being emphasized in assignments and labs, then it is fair to test students similarly on exams. It is also important to recognize that students need more practice, especially in test-style multiple-choice types of questions before encountering them on the exam because these questions have not been, to date, the norm. It is likely to promote deeper student engagement with laboratory and Interactive Lecture Experiments activities if they know these skills will also be tested on the exams. This may lead to more meaningful learning both in labs and through assignments. It would be interesting

What is the magnitude of the change of momentum of the 1 kg ball moving at the speed of 20 m/s perpendicular to the wall when it bounces **elastically** off it?

Fig. 7. Example of a traditional question, which tests student understanding of a perfectly elastic collision.

to investigate if using these data-rich questions during exams affects how students prepare for the exams and how they perceive the value of the data analysis skills learned in a physics class and their applications to every-day life.

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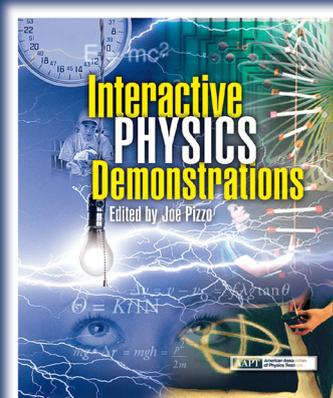
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