A Study of Assessment Writing

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Introduction and Motivation

“Teachers stink at writing exams.” This was a comment made by one of my fellow classmates last week during the modeling workshop. I agreed with him, at least for myself personally. I have been teaching at the college level four years and have been struggling with writing good exams all four years. In the beginning, my exams were very long, and were the typical multi-part, calculation-heavy exams found in traditional physics courses and textbooks. We teach how we were taught, after all! These exams were taking me days to grade every time I gave a new one. Being multi-part problems, oftentimes later questions relied on an earlier question that wasn’t clear or didn’t work out numerically if I made even a small mistake. Also, if students made a mistake in the earlier part, it threw the rest of their results off, making it extremely difficult to give partial credit as I would lose track of what they actually did correctly. These types of problems were also lacking in conceptual questions. I tried adding in open-ended, short essay questions along the lines of “Explain in physics term why....” but found out quickly that these were nearly impossible to grade (I felt that these questions were requiring the students to read my mind, not to mention I couldn’t read their handwriting)! So I worked on paring it down. This came with new problems, the biggest in my opinion was that the tests were too short and they didn’t test the same concept several ways to make sure the student didn’t just get lucky the first time around. To lessen my grading time, I turned many problems into multiple choice problems, but the majority of the questions tended to be verbal and math models and had too few diagrammatic and graphical representations. I sought feedback from my colleagues over the past year and a half and incorporated many of their suggestions but, while I believe my exams are much improved compared to the first years, I think there is still improvement to be made. I also know my colleagues wish to improve
their assessment writing skills as well and I hope that by writing this paper, conducting some research, and analyzing several of my past exams we will all be able to benefit from well-written questions that truly test our students’ understanding and not their math or memorization skills!

While I do wish to write tests that follow the modeling method, it is not my intent to review “best practices” or different instructional approaches in this paper. For example, I will not be discussing proper notation of forces in a force diagram, whether a dot on a motion map notates a position or a time period, or whether students should use bar charts or energy pies to diagram energy. Instead, the goal of this paper is to research commonalities among ‘good’ test questions and apply these tools to several of my previous exam questions.

**What constitutes a “good” test question?**

In general, a science assessment that focuses on conceptual understanding is known as a Concept Inventory (CI), the first and possibly the most famous (at least in physics circles) being the Force Concept Inventory. Concept inventories are almost always multiple choice problems and follow a basic format. For these multiple choice problems, each problem is known as an “item,” the question or statement that precedes the answer options is called the “stem,” and the answer choices are called the “response options,” hereafter known as options. Options are categorized as either correct or a distractor (incorrect option) (Libarkin, 2008). According to Libarkin, there are 3 main ways in which an assessment is considered valid (paraphrased from Libarkin, 2008):

- **Construct** - Is the topic covered in the item important for physics understanding?

- **Content** - From the perspective of an expert, does the item actually measure an aspect of physics understanding?

- **Communication** - Would the test taker interpret the item the same way as the test developer?
When writing the stem of an item, Libarkin suggests the following 3 rules of thumb: ask a question rather than making a statement or using fill-in-the-blank, write simply worded stems, avoiding parentheses and unnecessary commas, and use appropriate language (technical wording or not, depending on the audience). When creating the response options, use 3-5 options and avoid absolute statements such as “All of the above,” “None of the above,” and complex answers such as “Answers A and D, but not C” or “A is true because of C.” It is also important that distractors are credible, which comes from the test writer being familiar with common student alternative conceptions (preconceptions and misconceptions) and is usually the most difficult part of writing assessment items, according to Adams & Wieman (2010). And lastly, correct options and distractors for each item should have approximately the same length, same grammatical form, same level of technical wording, and distractors especially should not include absolutes such as ‘always’ or ‘never’ (Adams & Wieman, 2010). It is important to note that these are general rules but they are not set in stone; the rules can be bent if there is a good, defendable reason for it.

Two-tier questions are two multiple choice questions referring to the same scenario. The first is a more factual question (memorization) or may be a simple question or calculation. The second multiple choice item asks for a reason as to why the first answer was chosen or how the answer was obtained (Adams & Wieman, 2010). Two-tier questions are not necessarily appropriate for nationally utilized concept inventories, but they are much more useful in the classroom.

An alternative to multiple choice items would be open-ended questions. These questions can be very good at examining the student thought process on a certain topic and for recognizing common misconceptions in student thinking. According to Adams & Wieman (2010), these questions are best when written in words and terms that students themselves used during class discussions or interviews (teachers and experts tend to write questions more technical than necessary). A major downfall to this type of question is the amount of time needed to read and grade them; however, instructors can use answers from open ended questions to create future multiple-choice items since open-ended questions often make misconceptions more obvious.
Feedback on my previous exams

I handed out a couple of my previous exams to a colleague (a 10+ year modeler), a modeling workshop instructor, and a fellow modeling workshop participant for review. The following is a list of feedback that I received:

- When appropriate, define the system or have students define the system in the item.
- Greater variety in item type (not enough diagrammatic and graphical representations).
- When multiple choice options are force diagrams, have students label the forces in the one they chose.
- Have students do a quick sketch of a related graph (e.g. If given an x vs. t graph, sketch v vs. t).
- Have students back up a memorization question with a diagram or graph (e.g. When asking about momentum, have students draw the momentum map first of a specific scenario, then answer conceptual items about that momentum scenario).
- When a numerical answer is desired, avoid words such as “what is the...” or “determine.” Specifically ask the student to “calculate.”

Keys to a good physics modeling-based assessment

After studying the conceptual physics questions in Arons (1997) and Knight (2002), participating in the modeling workshop, and receiving feedback on my own exams, I believe the following items, used in conjunction with the aforementioned “good test writing rules,” are important aspects of writing an exam that supports the physics modeling method:

The test includes a fairly even distribution of all four models (graphical, mathematical, verbal, and diagrammatic). It should test the relationships of variables through these models, i.e. the relationships between position, velocity, acceleration, and time, the relationships between forces, position, and energy, and the relationships studied in particular lab experiments. It should test students on their ability to verbally describe these relationships both scientifically and in lay-person’s terms. Students should be tested on their
ability to set up mathematical models rather than just plugging numbers into equations. Assessment items also must test common misconceptions that have been discovered in previous research and are analyzed in the common concept inventories used at my school (FCI, MBT, and TUGK) without teaching to the test or duplicating CI questions. Lastly, words like ‘determine’ and ‘find’ should be replaced with the less ambiguous ‘calculate.’

**The test questions**

Putting the information together, I have chosen 8 questions (several are multi-part) from previous exams to analyze. In choosing these questions, I tried to get a variety of first-semester physics subjects, including kinematics, forces, momentum, and energy. For each question chosen, I first include a copy of the *original* version, then a written analysis of the *modifications* made and why, and finally a copy of the *new* and improved question. One will notice that some questions were only slightly revised while others have major changes. I have limited the number of open-ended questions mainly for one reason: time constraints in grading hand-written responses and short essays. Please note that, in order to conserve paper, not all graphs and diagrams are as large as I would have them on an exam for the students and I also did not leave space to actually work out each problem, as I would on a student exam. I also would number every item (even in multi-part problems) on the student’s exam, rather than labeling them with letters as I have done below, so that the students would not confuse parts of the problem with multiple-choice options.
The Items

1. Original: Consider the position vs. time graph to the right. What is the object doing during the time interval \( t=2-6(s) \)? (Circle all that apply)
   a. traveling at a constant velocity
   b. speeding up
   c. slowing down
   d. not moving
   e. moving in the negative direction
   f. moving in the positive direction, then turning around and moving in the negative direction

 Modifications: Too many options. I will remove the option “not moving” since students rarely choose that and it is not a common distractor. I will also add a second component requiring students to draw a velocity vs. time graph that corresponds with this position vs. time graph. I will also add in a question asking for the speed of the object at a specific time instant to test for ‘one-point slopes.’

 New: Consider the position vs. time graph to the right. What is the object doing during the time interval \( t=2-6(s) \)? (Circle all that apply)
   a. traveling at a constant velocity
   b. speeding up
   c. slowing down
   d. only moving in the negative direction
   e. moving in the positive direction, then turning around and moving in the negative direction

 Addition: What is the speed of the object at \( t=4(s) \)?
   a. 0(m/s)
   b. 1.25(m/s)
   c. 7.50(m/s)
   d. 5.00(m/s)

 New Follow-up: In the velocity graph to the right, draw the corresponding \( v \) vs. \( t \) graph during the \( \Delta t=2-6(s) \) time interval. You do not have to draw the portion of the graph for \( \Delta t=0-2(s) \) and \( \Delta t=6+(s) \).

2. Original: What is the weight of a 200(N) watermelon (magnitude only, not direction or units)?
   a. 9.8     b. 20     c. 200     d. 2000

 Modifications: I think this is a good question and shows whether or not students are reading the questions carefully. It also show how many students confuse weight and mass as so many students choose option b. The modification I would make though, would be a couple of follow-up questions on differentiating between \( F_g \), \( m \), \( g \), and \( a \).
Addition 1: Explain the difference (in words) between the variables $F_g$ and $g$. Be explicit; don’t just tell me what each of these is.

The graph to the right is similar to one we saw in one of the lab experiments. Three trials, a, b, and c, were performed and the data are plotted.

Addition 2: Which of the trials had the greatest acceleration?

Addition 3: Which of the trials used the largest masses?

Addition 4: What is the meaning of the slopes of these plots?

3. Original (2 related items):

You are standing on a raft in the middle of a pond. You leap horizontally from the raft and the raft recoils in the opposite direction. Assume that the raft is heavier than you. After you leap, which has a larger momentum: you or the raft?

a. They are equal  
b. The raft  
c. You  
d. Not enough information to solve

Same situation as the previous problem. After you leap from the raft, which has a larger speed: you or the raft?

a. They are equal  
b. The raft  
c. You  
d. Not enough information to answer

Modifications: The system needs to be defined. Also, these have the potential to be more of memorization-type questions so they need some sort of introduction and/or follow up questions to test the students’ conceptual understanding. Note: in my class, we call the opposite of an inelastic collision an explosion. I will also change option d. to be the same for both questions.

New: You are standing on a raft in the middle of a pond. You leap horizontally from the raft and the raft recoils. Assume that the raft is heavier than you, that both you and the raft are in the system, and that it is a perfectly inelastic explosion.

Addition 1: Draw qualitative, labeled momentum bar graphs and momentum motion maps roughly to scale to show each object (you and the raft) before and after the explosion. Note on your map which direction is positive.
Momentum Motion Maps:

Before:

After:

New: After you leap, which has a larger momentum: you or the raft?

   a. They are equal
   b. The raft
   c. You
   d. Not enough information to answer

New: After you leap from the raft, which has a larger speed: you or the raft?

   a. They are equal
   b. The raft
   c. You
   d. Not enough information to answer

Addition 2: If the raft is 5 times more massive than you, and has a speed of 0.5(m/s) after you jump, what is your speed after the collision? Show your work by starting with the conservation of momentum equation and show that the exact masses for each object are not needed (in other words, to receive full credit for the problem, keep the masses in terms of ‘m’ with respect to each other).

4. Original: If a semi-truck and a compact car collide head-on, which vehicle experiences a greater magnitude of force?

   a. The truck
   b. The car
   c. They feel an equal force
   d. Not enough information to answer

Modifications: This, like the last two, could be considered a more memorization-type question. It may also parallel FCI questions too closely. Instead of a verbal question, I will have the students draw a sketch of the force vs. time graph for two objects colliding: a car and the side of a brick wall. This should get the students thinking back to similar graphs they saw in class. I will also include a picture of the scenario for more visual students.
A car manufacturing company is testing one of their new cars. They attach a zeroed force sensor to the car and another to the side of a brick wall. The car is driven remotely in the positive direction at a very high speed and crashed into the wall. Draw a quick qualitative sketch of the force vs. time graph during the collision. Include both force sensor readings on the same graph but draw the car’s as a solid line and the wall’s as a dashed line.

5. **Original:** Using conservation of momentum arguments, explain why it is difficult for a firefighter to hold a hose which ejects large amounts of high-speed water.

**Modifications:** Difficult to grade verbal explanations. Change the problem so that students explain using momentum bar graphs and/or momentum motion maps.

**New:** Draw qualitative, labeled momentum bar graphs and momentum motion maps to explain why it is difficult for a firefighter to hold a hose which ejects large amounts of high-speed water.

**Event:**

<table>
<thead>
<tr>
<th>Event</th>
<th>Initial object/mass/velocity</th>
<th>Final object/mass/velocity</th>
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</tbody>
</table>

**Motion Map:**

**Initial:**

**Final:**
6. **Original:** Consider the position vs. time of a jellyfish (to the right).

   a. Write the specific math model(s) for the position vs. time graph for the entire time interval shown. For section c, you must calculate the y-intercept for full credit. You may not estimate it from the graph!

   b. Fill in the velocity vs. time graph to the right and fill in the motion map below. Make sure to include ALL labels!

   c. Write the specific math model for the velocity vs. time graph from t=0-5s.

   d. **Using the velocity vs. time graph,** calculate the TOTAL displacement of the jellyfish. Show your work! Next, calculate displacement from the x vs. t graph. Do your answers match?

   e. Between 5 and 8 seconds, what is the jellyfish doing?

**Modifications:** There are some formatting problems with this item. First, the students are asked to draw a motion map in part b, but the blank motion map scale is at the bottom of the page. Also, part b really contains 2 components that should be split into two separate items. The position function is only taking up a small portion of the graph and, while not incorrect, it may be easier to read if the majority of the graph area is utilized. I think a graph with less horizontal and vertical tick lines may be better as well. There should be less emphasis on the math models so I will move them towards the end of the problem, after the more qualitative questions. I will also add an item that tests the verbal description of the graph (or at least part of it).
**New:** Consider the position vs. time of a jellyfish (to the right).

a. Which of the following describe the jellyfish’s motion during the time interval \(\Delta t=0-6\) (circle all that apply)?
   a. traveling at a constant velocity
   b. speeding up
   c. slowing down
   d. moving in the negative direction
   e. moving in the positive direction

b. Calculate the slope of segment a.

c. In lay-person’s terms, what is the slope of segment ‘a’ telling us (be specific)?

d. Create a *quantitative* motion map for the jellyfish’s entire motion below. Make sure to include ALL labels!

e. Write the specific math model(s) for the position vs. time graph for the entire time interval shown. For segment c, you must *calculate* the y-intercept for full credit. You may not estimate it from the graph!

f. Draw the corresponding quantitative velocity vs. time graph.

g. *Using the velocity vs. time graph only*, calculate the TOTAL displacement of the jellyfish. Show your work!

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**7. Original:** You want to go to the beach and decide to transport all of your equipment with a sled. Your 175(N) pull on the sled makes a 20° angle with the ground as you pull with constant velocity. The sand has a coefficient of kinetic friction with the sled of \(\mu=0.85\).

a. Draw an interaction and force diagram *to scale* for this scenario. What’s your object of interest?

b. Set up your two sum force equations.

c. Looking at the equations in part b, what do you know about the magnitude of the force of friction?

d. Find the mass of the sled and its contents.
**Modifications:** Item a. has two questions in one; those should be separated. I will also add in the idea of action-action pair here so have the students draw two interaction and two force diagrams. This part should specify to include labels on the force diagram. In part b. I will specify to keep the force equations in terms of labeled force variables and ask what each equation is equal to. I will slightly reword the last question to be more specific. This is a problem that could also be easily modified for non-constant velocity. If I decided to do that, I would add in an item that has the students draw a motion map.

**New:** You want to go to the beach and decide to transport all of your equipment with a sled. Your 175(N) pull on the sled makes a 20° angle with the ground as you pull with constant velocity. The sand has a coefficient of kinetic friction with the sled of µ=0.85.

a. Draw 2 interaction diagrams and 2 force diagrams: 1 each for you and 1 each for the sled. The force diagrams must be drawn to scale with respect to each other and the forces labeled. Assume your mass is greater than that of the sled.

b. Set up your two sum force equations in terms of labeled force variables (don’t plug any numbers in) and specify what each equation is equal to.

c. Looking at your equations in part b. What do they tell you about the magnitude of the force of friction?

d. Calculate the mass of the full sled.

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**Original:** A toy rocket, sitting on a spring-loaded launch pad has a mass of 0.15(kg). The spring launcher has a spring constant of 500.0(N/m). Right before launch, the spring is compressed by 15.0(cm). After launch, the rocket reaches a maximum height above the ground and then falls vertically back to the launch pad. Assume a closed system with the rocket, earth, and spring, no air resistance, and vertical motion only. The rocket is launched ONLY by the spring. Note: the picture may not be to scale.

a. Which of the following trios of energy pies would best describe the three rocket positions shown in the figure to the right, assuming the rightmost figure is at y_{max}?
b. Calculate the total energy in this closed system.

c. Using energy conservation, calculate the maximum velocity of the rocket.

d. Which of the following force diagrams best represent the rocket at $y_{\text{max}}$.

\begin{itemize}
  \item [a.] \hspace{2cm} [Force Diagram A]
  \item [b.] \hspace{2cm} [Force Diagram B]
  \item [c.] \hspace{2cm} [Force Diagram C]
  \item [d.] \hspace{2cm} [Force Diagram D]
  \item [e.] \hspace{2cm} [Force Diagram E]
\end{itemize}

e. Using energy conservation, what maximum height does the rocket reach after launch?

**Modifications:** For the most part, I think this problem is fairly good as it stands, to study conservation of energy. One addition I would make is to have the students label the forces in the diagram that they choose in part d (since this is testing for the “impetus” force idea). Another addition that could be made is to add a motion map and/or kinematic stack to describe the rocket’s motion. To avoid these long multi-part problems, I will break into qualitative (energy pies, force diagrams, and motion map) and then quantitative parts (calculations).

**New:** A toy rocket is sitting on a spring-loaded launch pad. Right before launch, the spring is compressed. After launch, the rocket reaches a maximum height above the ground and then falls vertically back to the launch pad. Assume a closed system with the rocket, earth, and spring, no air resistance, and vertical motion only. The rocket is launched ONLY by the spring. Note: the picture may not be to scale.

a. Which of the following trios of energy pies would best describe the three rocket positions shown in the figure to the right, assuming the rightmost figure is at $y_{\text{max}}$?

\begin{itemize}
  \item [a.] \hspace{2cm} [Energy Pie A]
  \item [b.] \hspace{2cm} [Energy Pie B]
  \item [c.] \hspace{2cm} [Energy Pie C]
  \item [d.] \hspace{2cm} [Energy Pie D]
\end{itemize}
b. Which of the following force diagrams best represent the rocket at $y_{\text{max}}$.

a. 

b. 

c. 

d. 

e. 

c. On the force diagram you chose above, label each force vector.

d. On the vertical scale to the right, draw and label a qualitative motion map for the rocket.

e. On your motion map, label the three different positions shown in the picture:

   a: the instant before the spring launches (spring is at maximum compression)
   
   b: the instant the spring is back to equilibrium and the rocket is just disconnecting from spring
   
   c: the instant the rocket reaches maximum height

Addition (quantitative separate problem): Same scenario as above. The toy rocket has a mass of 0.15(kg). The spring launcher has a spring constant of 500.0(N/m). Right before launch, the spring is compressed by 15.0(cm). Assume a closed system with the rocket, earth, and spring, no air resistance, and vertical motion only. The rocket is launched ONLY by the spring.

a. Calculate the total energy in this closed system.

b. Using energy conservation, calculate the maximum velocity of the rocket.

c. Using energy conservation, what maximum height does the rocket reach after launch?
References:


