# In Search Of Alignment: Matching Learning Goals And Class Assessments

David T. Brookes[*] and Eugenia Etkina[†]

[*]*Department of Physics, Florida International University, 33199*
[†]*Department of Learning and Teaching, Rutgers University, 08901*

**Abstract.** Traditionally, the goals of physics courses focused more on helping our students master the normative physics knowledge and not so much the process through which this knowledge is constructed. We argue that the process itself is the heart of physics and cannot be separated from the outcome. In this paper, we suggest not only to rethink the goals of the courses but also to rethink the traditional paper and pencil tests. Specifically, we would like to show how the traditional summative assessments could be transformed to match our new learning goals. The work described in the paper is done in the context of ISLE – Investigative Science Learning Environment whose main goal is to connect the process of physics to the final knowledge by engaging students in the activities that mirror scientific practices while they are learning new normative knowledge.

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## INTRODUCTION

Science is a field of study that involves creating new knowledge about nature through symbiotic processes of experimenting and theoretical modeling (both qualitative and quantitative). In science, experiments are used to test theoretical models and as a source of new/surprising results that drive scientists to develop new theoretical explanations or models.

Traditionally, classroom learning of science (or physics) has been considered to be an act of learning about the final outcome of this scientific process (called normative knowledge) and was considered separate from the scientific process itself. The extreme version of this separation can be seen in a high school physics classroom where the students spend the first month of instruction learning about the "scientific method", significant digits, and error analysis. The rest science has been challenged. At all levels of instruction, the more and more inseparable — "in science, content and process are inextricably linked of the school year is spent memorizing how to apply specific equations to solve well-defined back-of-the-chapter problems, and doing cook-book labs. process and the final outcome of this process are becoming Recently, this dichotomy of learning versus doing [1]." The guide for K-8 science instruction [2] describes students proficient in science as those who

1. "Know, use, and interpret scientific explanations of the natural world;
2. Generate and evaluate scientific evidence and explanations;
3. Understand the nature and development of scientific knowledge; and
4. Participate productively in scientific practices and discourse."

In addition, the report says "… quality instruction should promote a sense of science as a process of building and improving knowledge and understanding. Students should have experiences in generating

**TABLE 1.** Science learning goals for middle and high school students

| Grades 5-8 | Grades 9-12 |
|---|---|
| • Design and conduct a scientific investigation.<br>• Use appropriate tools and techniques to gather, analyze, and interpret data.<br>• Develop descriptions, explanations, predictions, and models using evidence.<br>• Think critically and logically to make the relationships between evidence and explanations.<br>• Recognize and analyze alternative explanations and predictions.<br>• Communicate scientific procedures and explanations. | • Use technology and mathematics to improve investigations and communications.<br>• Formulate and revise scientific explanations and models using logic and evidence.<br>• Recognize and analyze alternative explanations and models.<br>• Communicate and defend a scientific argument. |

researchable questions, designing methods of answering them, conduction of data analysis, and debating interpretations of data." These sentiments are echoed by National Science Standards that propose the fundamental abilities of inquiry recommendations for students in grades 5-12 as shown in Table 1 [3].

In addition, college graduates who become engineers are not evaluated on the basis of the content that they have mastered in their courses, but on the basis of experiences that they had in designing a system or a process, solving complex problems and communicating [4].

The above examples show that we cannot continue doing business as usual by focusing on students mastering normative physics knowledge. We have to holistically rethink our approach to physics education starting with its goals. These examples suggest that our goals need to also reflect what we want our students to be able to *do* when the leave our course. To design curriculum materials and learning environments, we need to think of what the achievement of our learning goals will look like. In other words, what evidence can we collect to find whether the goals have been met [5]? Only when we have set our goals and have a clear picture of how we can measure their achievement in students can we devise the intermediate step between the goals and evidence of the achievement of the goals – the instructional materials and formative assessment strategies.

## GOALS AND ASSESSMENTS

The PER community has developed a large array of assessment instruments to assess students' conceptual understanding via multiple-choice tests with effective distractors. Through those instruments we learned about specific conceptual difficulties and later devised curriculum materials to target those. In addition, several groups developed assessment instruments that allow the instructors to assess students' development of experimental abilities [6], multiple representation abilities [7] and problems solving abilities [8]. These instruments have helped us learn how long it takes for a student to develop a particular ability, what abilities are especially challenging and how tweaks in the curriculum materials lead to the more robust development of abilities [9]. However, these instruments are either used for research purposes or as supplements to traditional paper and pencil exams. The nature of our traditional exams remains unchanged. They often pose traditional back-of-the-chapter problems and thus send messages to the students about what we really value. In this paper, we suggest not only that we need to rethink the goals of the courses but to rethink the traditional paper and pencil tests [10]. Specifically, we would like to see if the traditional summative assessments can be transformed to match our new learning goals.

This work is done in the context of ISLE – Investigative Science Learning Environment whose main goal is to connect the process of physics to the final knowledge by engaging students in the activities that mirror scientific practices while they are learning new normative knowledge. In this approach, students repeatedly devise multiple hypotheses to explain collected data, design experiments to test those hypotheses, evaluate assumptions that they used to make the predictions, communicate with each other as they work in groups and finally reflect on the process of knowledge construction and application [11]. The purpose of these activities is to help students develop "scientific habits of mind" or scientific abilities which include but are not limited to a) hypothetico-deductive reasoning, b) identifying and evaluating assumptions, c) making a judgment about an experimental result including the effects of uncertainties and assumptions, d) designing and analyzing an experiment to answer a specific scientific question, e) representing physical phenomena in multiple ways, and f) evaluating a result using a limiting case or other means [12].

In addition to these scientific habits of mind, we identified the following learning goals for our students. By the end of the course students should be able to

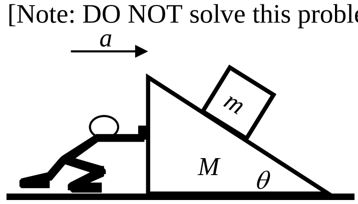
1. Learn independently and acquire new knowledge.
2. Think creatively and innovatively in new and novel situations.
3. Apply physics knowledge to solve real-world problems and to understand how the real world works from a physics perspective.
4. Work and learn effectively as a team (in groups of 3 and as a whole class).

How can we assess using traditional paper and pencil exams whether students are developing these scientific habits of mind and achieve the goals of the course? Below we will give four examples of exam questions that attempt to assess the goals listed above and show a few examples of student work. The course in which the questions are being used is a small enrollment (30 students) calculus-based general physics course.

### Example 1: Evaluating Question

The following problem directly assesses students' ability to evaluate a result by taking a limiting case. Note that the students are asked NOT to solve the problem but to evaluate the solution.

**Consider the following problem**: David is pushing on the triangular block (mass *M*) and the entire system accelerates to the right as shown in the diagram. What force must David exert on the triangular block so that the smaller block (mass *m*) remains stationary relative to the triangular block? Assume no friction between any surfaces. [Note: DO NOT solve this problem.]




Juan, who is very good at physics, but has forgotten his high school geometry, got confused when he set up his co-ordinate system - he can't tell which angle is $\theta$. As a result, he can't tell whether to take sine or cosine when breaking some of the forces into components, so he has come up with two alternative answers to the problem:

$F_{\text{David on M}} = (M+m)g\frac{\sin\theta}{\cos\theta}$, or $F_{\text{David on M}} = (M+m)g\frac{\cos\theta}{\sin\theta}$

Use a special case/limiting case to help Juan figure out which answer is the correct one. Remember to be explicit in your reasoning: What is the special case you're considering? What do you intuitively expect the answer to be for this case? Then try out both equations and explain which one is more likely to be the correct answer.

## Example 2: Experimental Design Question

Experimental design questions are a powerful way to assess more than one learning goal for our students. In our view, an ideal design question is minimally specified and open-ended in the sense that there are multiple correct answers. This allows students to apply their physics knowledge to a real-world situation, demonstrate their ability to co-ordinate multiple scientific abilities at once, and demonstrate their ability to innovate and think creatively. We include one example from our exams below:

**Question**: In the barber or hairdresser, there is a large mirror on the wall for each station. Once the haircut is finished, the barber/hairdresser has a little mirror that he/she uses to allow the customer to see the back of his/her head. Should the barber/hairdresser i) have the customer face the large mirror on the wall and use the small hand held mirror behind his/her head, or ii) have the customer face away from the wall and hold the small mirror in front of them? Justify your reasoning with ray diagrams.

## Example 3: Evaluating Assumptions Question

One of the most challenging scientific habits of mind that students acquire is the ability to identify and evaluate assumptions. In ISLE language, "assumptions" are the factors that we choose to ignore when constructing a model of a particular situation, or conducting an experiment. The most obvious example of an assumption is the decision to ignore friction or air resistance.

**Question**: A rail gun is going to be used to launch small satellites into orbit around Earth. An engineer presents the following analysis for this real-life application:

*The system consists of the satellite and Earth. The rail gun is external to the system and does work on it. The initial state is just before the satellite is launched, the final state is when the satellite is in orbit. In setting up the problem this way I assumed the following:*
*1. I ignored the rotation of Earth, 2. I ignored air resistance, 3. I assumed the rail gun is working properly, 4. I assumed Earth is a sphere.*

a) Which of the assumptions are relevant to implementing this application problem and which assumptions are completely irrelevant? Explain why
b) Out of the relevant assumptions, which assumption do you think is valid and which assumption do you think is not valid? Explain why.

## Example 4: Multiple Representation Question

**Question**: Consider two balls dropped from the same height but the second one is released a short time Δt after the first one. What happens to the distance between ball 1 and ball 2 (as a function of time) as they fall? Discuss using a motion diagram, an *x* versus *t* graph, and equations. Discuss the consistency between your representations.

# RESULTS AND ANALYSIS

We coded every question we set on each exam for which goals they achieved and the overall results of this coding are presenting in Table 2. Inter-rater agreement was 100% after discussion.

## Student Responses

The limitations on the length of the paper do not allow us to show multiple examples of what students said during interviews about the exams. We show just one example in which italicized portions highlight the student's understanding of the goals of the exam:
"… But you know it and the best example was the last exam, with the barber shop...I *didn't know that I knew that question and I literally reasoned it out*…And when I found I got full points I was like, "Wow." Because I remember…during the exam, I was like,

**TABLE 2.** Table of measured goals for all exams administered over a two-semester period. The numbers indicate the number of times that each learning goal was assessed by the questions posed in each exam.

| Goal | Mid-Term 1 Semester 1 | Mid-Term 2 Semester 1 | Final 1 Semester 1 | Mid-Term 1 Semester 2 | Mid-Term 2 Semester 2 | Final Semester 2 | Total |
|---|---|---|---|---|---|---|---|
| H-D reasoning | 1 | 1 | 0 | 0 | 0 | 2 | **4** |
| Assumptions | 1 | 0 | 3 | 1 | 1 | 3 | **9** |
| Uncertainties | 1 | 0 | 2 | 1 | 1 | 1 | **6** |
| Representations | 3 | 1 | 0 | 0 | 5 | 3 | **12** |
| Exp. design and analysis | 2 | 0 | 2 | 3 | 3 | 4 | **14** |
| Evaluation | 1 | 2 | 2 | 1 | 0 | 1 | **7** |
| Independent learning | 0 | 0 | 2 | 0 | 1 | 2 | **5** |
| Creativity | 1 | 2 | 4 | 2 | 2 | 3 | **14** |
| Apply physics | 2 | 3 | 7 | 4 | 6 | 5 | **27** |
| Work as a team | 1 | 1 | 1 | 1 | 1 | 1 | **6** |

"*You threw this out of nowhere*…this is weird." And I realized *that I was able to reason it out*. That to me was the biggest accomplishment I've had in this class. Because… like I stared at that question and I was like, "What is going on?" And I skipped it and I would go back to it, "What is going on?" And I'd go back to the other question and keep on going, come back, "Oh my God, I'm never gonna get this question." And then to have that moment that you're just like, "You know what? I'm gonna take it step by step. *I'm gonna do the analyzing we normally did with the mirrors and just figure it out and work through it." And it worked. And to see that it worked – it made everything worthwhile*."

## DISCUSSION

The purpose of this paper was to start a conversation about changing our traditional mid-term and final exam questions to match the changing goals of our courses. One might argue that the examples of the problems that we showed require time consuming grading, that it is impossible in large enrollment courses. At Rutgers University we have a 200-student algebra-based course where we give exams with questions similar to those shown in the paper. The exams are graded by the course professor and the TAs. To reduce the workload on the TAs the course instructor chose to revise the grading of the labs and homework in order to free up the TAs time. If we see assessment as the integral part of instruction not an add-on, then we can find the time!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