Assessing-To-Learn: Formative Assessment in Physics Instruction

Robert J. Dufresne and **William J. Gerace,** University of Massachusetts at Amherst, Amherst, MA

Assessment designed to enhance teaching and learning is called "formative assessment." During formative assessment, teachers and students seek information about the state of student learning and then use the acquired information to adapt teaching and learning to meet student needs. "Classroom formative assessment" (CFA) requires that teachers explicitly engage in formative assessment during classroom learning activities. At a basic level, CFA occurs naturally and is a common part of most instructional settings. Nevertheless, the systematic practice of CFA is rare in secondary and post-secondary science education. Here we provide suggestions for those interested in formative assessment for use in teaching introductory physics. A simple model of classroom formative assessment is presented. Included are examples of formative assessment activities and suggestions for implementation.

The rationale for doing systematic formative assessment is extensive.[1-3] Summative assessment, which occurs primarily through the use of periodic cumulative exams that test for information and low-level problem-solving skill, encourages rote learning on the part of students and cannot be used by teachers to shape instruction in a continuous and dynamic fashion. To effectively monitor and influence the development of students' thinking processes, inquiry skills, attitudes toward science, and learning behaviors requires continuous forms of assessment integrated into everyday learning activities.

A Simple Model for Classroom Formative Assessment

In this section, we briefly describe an approach for structuring CFA activities for use in teaching introductory physics. We will refer to this approach as "Assessing-to-Learn" (A2L).[4] In the next section we provide several examples of formative assessment items and illustrate how the items relate to identifiable cognitive goals. Our intent here is to provide a starting point for those interested in implementing formative assessment in their classroom.

A2L uses formative assessment materials designed for use with a classroom communication system (CCS).[5-8] CCSs permit: (1) presentation of questions to the class, (2) collection and storage of individual student answers, (3) anonymous display of a histogram of students' responses, and (4) a permanent record of each student's progress. Implementation of the A2L instructional approach varies from teacher to teacher, but in its simplest form, it consists of having students engage in learning activities or problem-solving tasks related to a question presented to them. Depending on the activity, students work individually or in small groups. As students work on an activity, the teacher spends time with individual students or small groups, responding to student work. After an appropriate amount of time has passed, students enter a response to an assessment question. The answers are passed along to a computer at the front of the room. CCS software then generates a histogram that the instructor displays to the class.

Viewing the distribution of answers reinforces

DOI: 10.1119/1.1804662

the fact that there is generally disagreement among students, which is used to stimulate student interest. The display of the histogram is a tool for initiating class-wide discussions of the ideas and methods used by students to address the assessment question. During class-wide discussion, some students volunteer their reasoning, while other students offer rebuttals and elaboration. The instructor moderates the discussion and ensures that closure is reached. Based on the information received, the teacher and students redirect the learning activities. When appropriate, students are asked to reflect and report on the state of their learning.

The A2L approach shares a number of features in common with other active-learning approaches (with and without a CCS) that attempt to promote interactivity in the physics classroom.[5,6,9-11] Nevertheless, the primary goal of CFA—to gain information about student understanding in order to enhance student learning—is unique. To achieve this goal, CFA focuses on the interactions between the teacher and small groups, on the class-wide discussion, on flexible teaching, on feedback to students, and on student self-assessment of their own work and understanding. The pursuit of this goal raises important questions: What kinds of information should be sought? What types of assessment questions yield suitable assessment information? How can the information gained be put to use to enhance student learning? Some insight to these questions can be gained by examining a few examples of formative assessment questions.

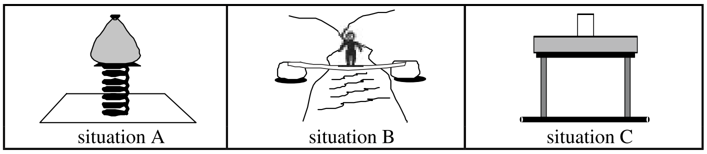
Examples of Assessing-to-Learn Items

Exploring Naive Concepts

Students come to their physics classes with a tremendous amount of experience and understanding. A great deal of this prior knowledge is in conflict with formal physics concepts and principles. Students need to become aware of their prior conceptions, have the opportunity to express their understanding, and hear what other students think. Likewise, it is essential that teachers become aware of students' pre-instructional understanding so they can better tailor learning activities to address their students' particular needs.

We often create A2L items for use prior to formal instruction on a particular topic. An example of this

Which pairs of objects are interacting?



Question 1. In situation A: water balloon and spring. Answer: Yes or No
Question 2. In situation A: water balloon and Earth. Answer: Yes or No
Question 3. In situation B: child and plank. Answer: Yes or No
Question 4. In situation B: child and rocks. Answer: Yes or No
Question 5. In situation C: block and table. Answer: Yes or No
Question 6. In situation C: block and Earth. Answer: Yes or No

Fig. 1. Recognizing the interaction between two objects.

type of assessment item is shown in Fig. 1.[12] The item is a set of six questions using an extended set of contexts that address the issue of perceiving interactions. Perceiving interactions is a necessary first step in identifying the forces exerted on an object or system. An interaction between two objects is usually perceived through the effects the objects have on each other (for example, sometimes the motions of the objects are changed, sometimes the objects' shapes are changed, sometimes both). Students may perceive interactions when there are changes in the shape of objects, especially when the objects return to their "natural" state when they are no longer interacting (as would be the case for the water balloon and spring in situation A). However, when there is no motion and neither object is perceptibly deformed, students are less likely to perceive an interaction.

Honing and Clustering

When students first learn a formal physics concept, they do so in a limited context and in isolation from other closely related ideas. Over time the students are expected to generalize their understanding of a concept and integrate it with other knowledge so that they can apply the concept in a wide range of contexts.

Some examples of possible Honing and Clustering assessment items are shown in Fig. 2. Figure 2(a) provides an example of how an assessment item can be structured so that students compare and contrast situations involving several concepts (e.g., pressure, force, buoyancy, and weight). An important feature of this item is that after students compare, predict, and discuss what will happen in each situation, they can actually carry out an experiment. In a second example shown in Fig. 2(b), the student is being asked to relate

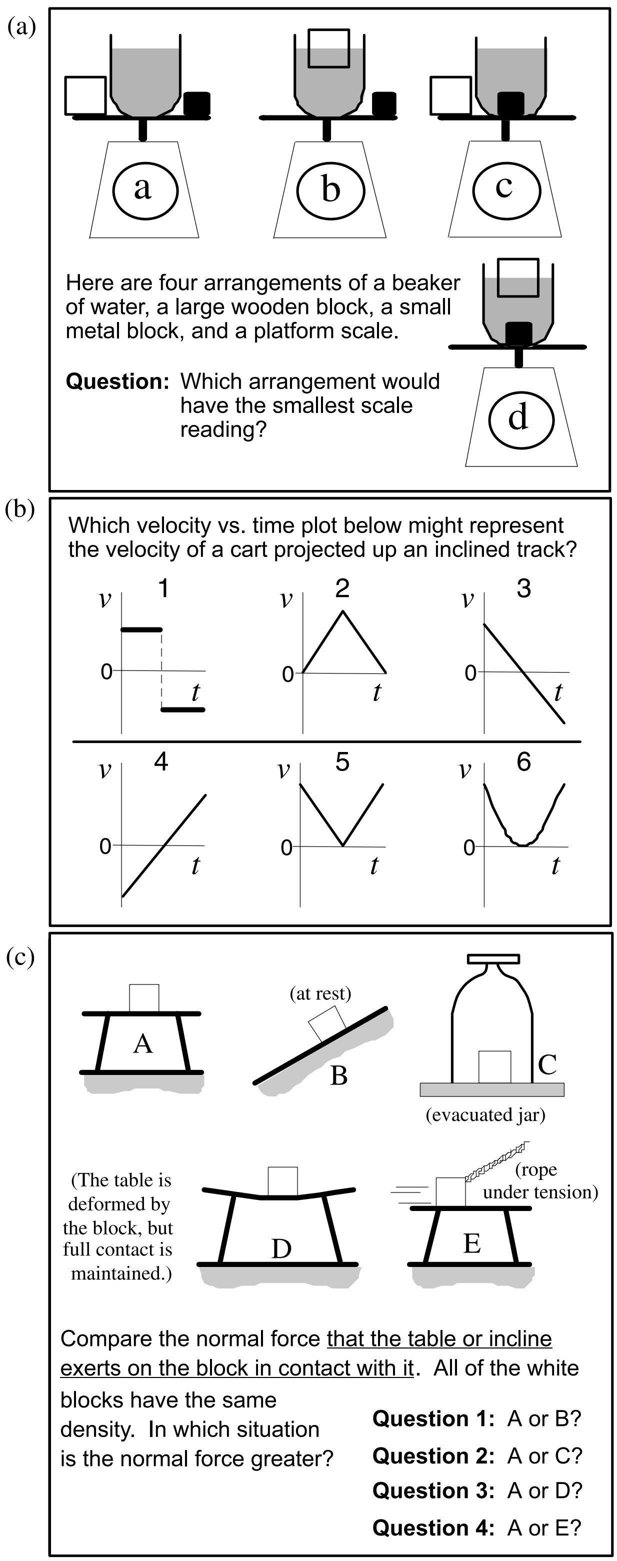


Fig. 2. (a) Comparing scale readings. (b) Associating motion with graphs of velocity vs time. (c) Comparing magnitudes of the normal force.

features of a graphical representation of velocity to a description of a physical situation. The item in Fig. 2(c) is a set of questions that explore students' understanding of a basic concept (normal force) in a diverse set of situations, some of which are known to elicit misconceptions.

Analyze and Reason Using Concepts

Once students understand a concept (or set of concepts), an important goal is to get them to use their understanding to analyze and reason about more complex situations. By analysis, we simply mean to break a situation down into basic parts to better understand the whole. Reasoning involves putting together the parts to draw conclusions or make judgments. Analyze and Reason assessment items require students to deal with complex situations and questions that can be addressed qualitatively, but would be extremely difficult for them to solve using an equation-centered approach. Some of these items may be open ended, requiring students to make assumptions and set goals.

Figure 3(a) shows one example of an Analyze and Reason assessment item that is more open ended than some of the previous examples. Students are given a motion (strobe) diagram of a thrown ball showing velocity vectors at each point and are asked to deduce whether air resistance is significant. Students must decide what features of the strobe diagram they should analyze to gain information about air resistance, and they must decide on some criterion for determining whether air resistance is significant. Figure 3(b) contains a second example of an Analyze and Reason item in which students must use an alternate representation. In the example, students are shown four different electric field diagrams. For each diagram a charge undergoes a displacement. Students are asked to determine the situation for which the work done by the field on the charge is zero. Figure 3(c) shows an example where students must compare and contrast the motion of, and the forces exerted on, a set of blocks under three different conditions. Finally, in Fig. 3(d) students are asked to compare the size of electrical forces given a continuous distribution of charge.

Concept-Based Problem Solving

A goal of instruction is to improve students' ability to use their knowledge of physics concepts to solve both quantitative and qualitative problems. In most traditional courses students focus so much on the algebraic aspects of problem solving, they never learn how to use physics concepts to solve problems. To focus students' attention on concepts during problem solving, we require them to describe and assess how various concepts and principles could be applied to solve a problem. A traditional problem, such as the one in Fig. 4, can serve as the basis for a discussion of students' problem-solving approaches. Taking the system to include both carts, college-level students can often determine the net force to be the difference of the two applied forces, and divide by the total mass to get the acceleration. Most students are unable to answer question 2 correctly, however, even though this requires only the application of Newton's second law to cart B (alone) using the acceleration found for question 1. Many students abandon the physics they have learned and instead rely on their intuition.

Figure 5 shows an item presenting two procedures for solving a given kinematics problem. For each procedure the students are asked to determine whether or not the procedure is valid, and if it is not valid, to identify which of the indicated steps is inappropriate for solving the problem. This type of item can be used to make students aware of common mistakes and misunderstandings. Similar items can also be used to address issues of scientific literacy. Reading and writing in science often requires skills (such as, following complex reasoning, evaluating claims, and identifying assumptions) not often practiced by students.

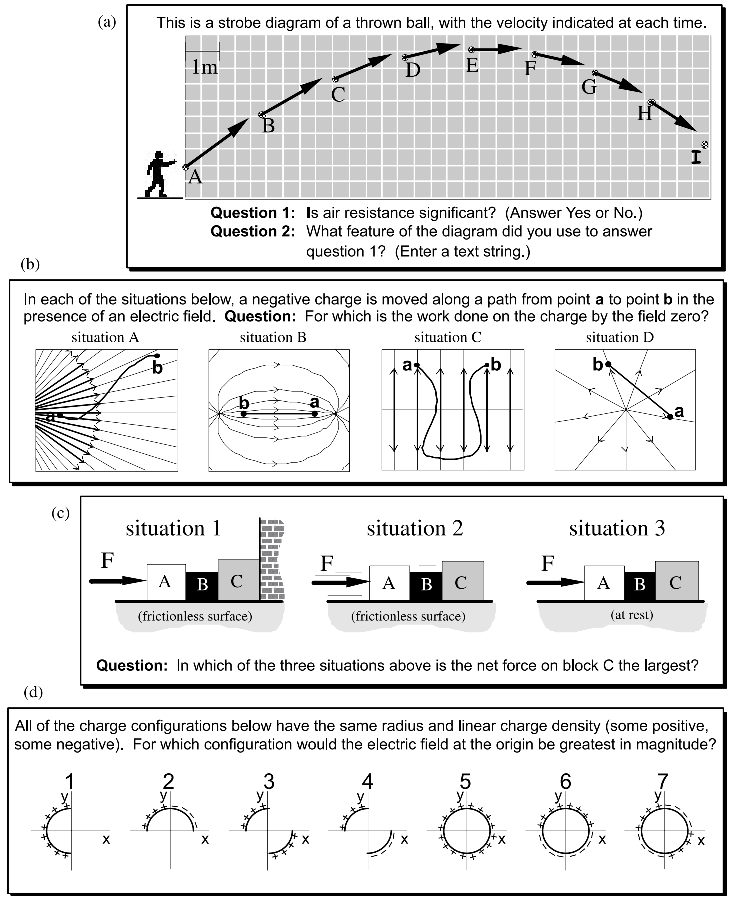


Fig. 3. (a) Reasoning about forces using Newton's second law. (b) Reasoning about electrical potential energy using field diagrams. (c) Analyzing a system of three blocks on a horizontal surface. (d) Comparing the size of electrical forces.

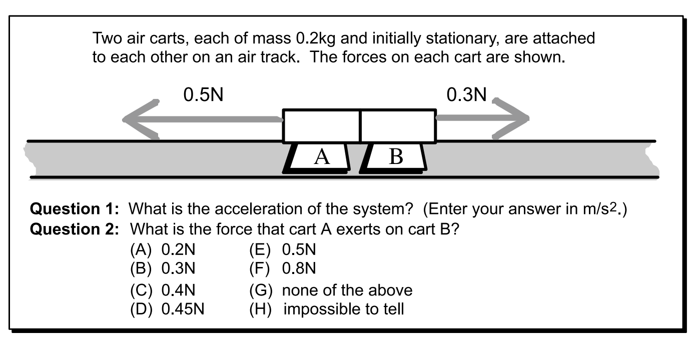


Fig. 4. Problem solving with Newton's laws.

Organize and Interrelate Groups of Concepts

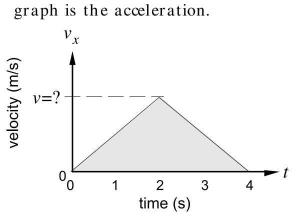
Figure 6 presents an item in which students are asked to compare two problems. The item proceeds in three parts. First students decide whether they would solve the two problems using a similar approach. For each problem, students then identify a principle that could be used to solve the problem. After a class discussion of the reasons for students' choices, students repeat the first part but with a different problem pair. The item helps teachers to determine what features of a situation students focus on when making decisions about how to solve a problem. It reveals the extent to which students can successfully choose an appropriate principle for solving a given problem, as well as the reasoning that students use in selecting a principle.

Toward Implementation—Some Final Thoughts

There is no simple recipe for implementing CFA. How a teacher responds to results from a particular

Problem: *Your little sister is playing with a toy car. She winds it up and lets it go. The car speeds up at a constant rate for 2s, then slows down at the same rate (also for 2 seconds) until it stops 3 meters away. What was the acceleration of the toy car for the first 2 seconds of its motion?*

Procedure I: (A) Draw a graph of the velocity of the toy car vs. time. (B) The graph starts out at zero and increases to a maximum of v at $t = 2$s, then decreases back to zero at $t = 4$s. (See diagram.) (C) The area below this graph is the displacement of the car, which is 3m. (D) So, equate the area below the graph to 3m, and solve for the unknown speed v. (E) The slope of the velocity vs. time graph is the acceleration.



Procedure II: (A) The acceleration of the toy car is constant and the same for the entire motion of the car. (B) The whole process takes 4 seconds, and the displacement is 3 meters, so use the formula:

$$\Delta x = v_{0x}t + \frac{1}{2}a_x t^2$$

where v_{0x} is zero, Δx is 3m, and t is 4s. (C) The only unknown in the equation is the acceleration a_x, so solve for it.

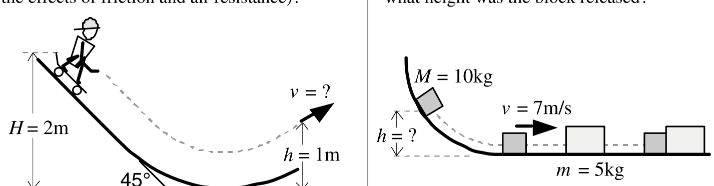
Question 1: If Procedure I is invalid indicate the invalid step. Enter V for valid.

Question 2: If Procedure II is invalid indicate the invalid step. Enter V for valid.

Fig. 5. Comparing solution procedures.

Problem A. A child on a skateboard is rolling down a ramp having straight and curved portions as shown. What is the speed of the skate boarder when she reaches the end of the ramp (if we ignore the effects of friction and air resistance)?

Problem B. A 10kg block is released from rest onto a curved frictionless track from an unknown height h. The block is traveling at 7m/s just before it collides and sticks to a 5kg block. From what height was the block released?



Question 1: Would you solve these two problems using similar approaches? (Answer Y for Yes or N for No.)
Question 2: What principle would you use to solve Problem A? (Enter a text string.)
Question 3: What principle would you use to solve Problem B? (Enter a text string.)

Fig. 6. Organizing physics principles around problem solving.

assessment item will in general depend on the learning priorities of the teacher and the readiness of the students.

Consider the assessment item in Fig. 2(a). This item could be used to probe students' awareness and use of interactions in their explanations of physical phenomena. After a class-wide discussion attempting to identify the conceptual understanding and reasoning behind students' choices, students could create the different situations to determine what actually happens in each case. A follow-up discussion could focus on changes in students' conceptual understanding and reasoning: (a) What has changed? (b) What caused the change? (c) Is the new understanding supported by the observations that were made? Students' new understandings could be put to a test by extending the context used in the assessment item. For example, one could ask students: (a) What would happen to the scale reading if a cylindrical wooden dowel was partially inserted into the beaker of water and held in place? (b) What if the cylindrical dowel was made of metal? Through this process the teacher can assess students' knowledge of interactions, so he or she can begin to address student needs in future learning activities. Students have the opportunity to assess the success of their current models of interactions and become aware of areas needing improvement.

CFA does not make learning physics easy. It is not a magic cure for the problems students face while learning physics. Instead it supports student learning and seeks to improve the processes students use to learn. Classroom formative assessment entails a shift in the classroom culture away from a teacher-centered, answer-dominated focus to a focus on students' mental processes as they are manifest in analysis and reasoning activities.

Teachers can take several steps to encourage the shift. Promote lots of student discussion. Give students adequate time to analyze situations and to formulate their own reasoning. Work with students' ideas and language while moving toward more formalized knowledge. Encourage discussion of a range of answers—some students are right for the wrong reason, and often students are "wrong" yet have many correct understandings to share. Highlight students' thinking processes and de-emphasize the importance of answers. Questions that require students to compare and contrast two or more situations can be used to shift the focus away from *what is the correct answer* to *why is the behavior the same/different*. By extending the context beyond familiar situations, students are nudged toward seeking connections between new and old situations. Intentionally vague questions break the tendency to be overly focused on *what is the correct answer*, since the correct answer depends upon the assumptions that the students make. Explain to students why you engage them in the activities that you do and what you expect of them. Help students adopt roles that will allow them to get the most out of their learning.

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PACS codes: 01.40Eb, 01.40Gb, 01.40H

Robert J. Dufresne *is a research assistant professor in the Department of Physics at the University of Massachusetts. He received his Ph.D. in nuclear theory from UMass in 1987. His research interests include assessment, instructional technology, and models of cognition. He is the coordinator of the Assessing-to-Learn materials development and teacher enhancement project.*

Department of Physics, Box 34525, University of Massachusetts, Amherst, MA 01003–4525; dufresne@physics.umass.edu

William J. Gerace *is professor of physics and the director of the Scientific Reasoning Research Institute at the University of Massachusetts. He received his B.S. from M.I.T. and his Ph.D. from Princeton University. His research interests include developing a cognitive model for the acquisition, storage, and use of knowledge, and teacher preparation.*

Department of Physics, Box 34525, University of Massachusetts, Amherst, MA 01003–4525; gerace@physics.umass.edu