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Formative and summative assessment in a physics class: Time to change

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Abstract: The paper describes alternative formative assessment techniques and their implementation in an introductory physics course. These techniques help students develop some abilities that are used by scientists and engineers: reflection on knowledge construction, question posing, statement evaluation, and convincing others in the viability of their knowledge.

Introduction

Formative and summative assessment tasks that we use in the course send messages to the students about what they should focus on, and provide feedback whether their efforts were successful. By changing assessment tasks we can shift the attention of our students to what we consider important. Black and Wiliam¹ showed that the learning gains from systematic attention to formative assessment, including feedback for the students, are larger than gains found for most other educational interventions. The goal of this paper is to discuss some possible formative and summative assessment tasks that can help students focus on issues relevant to the work of scientists and engineers.

These tasks have been used in the past three years at Ohio State University, Rutgers University and California State University (Chico)². Tasks and student responses and used in this paper are taken from the OSU data in the course for freshmen engineering honors students (FEH). In 1999-2002 the course followed the Investigative Science Learning Environment (ISLE) approach³ that helps students learn physics using strategies similar to those used by physicists to construct knowledge. These include: using experimental evidence for model constructions, model building and experimental testing of the models. ISLE students invent and test physics concepts, students learn very little from authority.

Achieving the goals of introductory physics instruction through assessment

In most courses students' grades are based on their scores on quizzes, exams and lab reports. Quizzes and exams focus on qualitative and quantitative problems. Lab reports require descriptions of experiments. PER-designed tests focus on the understanding of fundamental concepts (see FCI, CSEM, etc). These forms of assessment send the following messages to the

students: focus on the understanding of the concepts, and learn how to apply equations to problem solving and be able to record and interpret experimental results.

These are good messages. However the challenges of real life are different from well-defined course problems and well-structured lab experiments. ABET engineering standards and surveys of former physics majors conducted by the AIP suggest that our students need to learn to formulate and solve complex problems, design investigations and products, and work collaboratively¹. To be successful in these activities they need to learn how to reflect on the reasoning process, ask questions, self-assess and communicate effectively. To meet these challenges we want our students to focus on additional questions while learning physics content:

- a) How did I come to think this way?
- b) What do I still not understand?
- c) How do I assess myself?
- d) How do I make a decision?
- e) How do I convince somebody that something makes sense?

Students will consider these questions important if they appear as a part of homework, quizzes, and exams.

Examples of assessment instruments

I. Weekly Reports (WR)

WR are structured reflective journals in which students answer several questions:

1. What did I learn this week?
2. How did I learn it?
3. What remained unclear?
4. If I were the professor, what questions would I ask to find out if my students understood the material?⁴

WR are implemented in all ISLE courses. Students either hand in hard copies or submit

them on-line. Graders read the reports, provide feedback to the students and grade them on the basis of effort and clarity. WR encourage student reflection on the construction of knowledge and self-assessment. Analysis of the first two questions (reports of about 40 students in 1999/2000 were coded) revealed a relationship between student conceptual gains and their ability to reflect on the construction of knowledge. Work of May & Etkina⁵ showed that students who think that they construct concepts from evidence, by analogy or by building on known concepts achieve better results in a course even if they come with very low pre-test scores. However subsequent work of May⁶ (40 students from 2001) revealed that such relationships disappear when students are not given regular feedback - students cannot reflect meaningfully. Thus, the ability to reflect was a learned ability. Just asking students to reflect without teaching them how to do it does little. This result suggests that we need to devote special attention to reflective tasks if we want our students to master this skill.

Harper, Lin and Etkina⁷ showed that WR encourage students to ask questions. The quality of the questions they asked related to their conceptual gains; the number of questions asked did not. For example, focus on formula-oriented questions correlated negatively with conceptual gains.

There are a number of problem with using WR in a large-enrollment course. The feedback must be provided to the students on a regular basis and graders (readers) of the reports should be trained to provide constructive feedback. The lack of both leads to the loss of the effectiveness of this tool. However, with the widespread use of electronic submission of regular homework problems it is possible to use recitation or lab TAs with special training to work with their students' WR on a regular basis and even to use students' questions in subsequent class meetings.

II. Problem posing

Problem posing activities are less time consuming and easier to grade. Students learn how to do it in the last part of WR, but separate problem posing tasks are possible. For example the students are given a picture of a situation and are asked to pose a physics problem based on

this situation. Another example is when students need to pose a problem that can be used for assessment of their peers' understanding of a particular concept. The analysis of the problems posed by the students allows the professor to see whether the problems are relevant, solvable, and whether students understand the physics. Students receive feedback and grades for this work. These tasks can be a part of a regular homework or quizzes.

The following is an example of a problem-posing task used on the first midterm exam in an E&M quarter at OSU (2002). The class consisted of three sections (about 70 students each). The average CSEM post-test scores in the three sections on this relatively difficult test were 72%, 71%, and 70%. Students were asked the following problem posing question. "Suppose you have a system with two electrically charged objects in it. If you were the professor, what two questions would you ask your students to determine if they really understood possible system changes that would lead to a decrease in the system's electric potential energy?"

The goal of the assignment was to determine whether the students realized that the energy depends on the signs of the charges, the magnitudes of the charges, and on their relative separation. If students recognized the dependence of energy on the charge magnitude and separation, they scored 50%, if they also recognized the importance of the sign, they scored 100%. Below we provide one of the better responses.

- (a) If two like charges are near each other, what directions would they need to be moved to decrease the electric potential energy? Why?
- (b) If two unlike charges are near each other, what directions would they need to move to decrease the e-p energy? Why?

The scores of three sections of FEH on these activities were: 65%, 71%, and 73%.

These scores are comparable to the average scores for the CSEM - these are talented and hard working students. Almost all of them posed answerable questions that could be used on exams. Thus students can master the skill of problem posing. But a close look at the average scores shows that sign dependence was not

recognized by the majority of the students as an important factor.

III. "How do I make a decision?" tasks

Decision making tasks involve a situation in which a student needs to make a decision about a process or a product. Here is a sample problem: "Your little sister received a motorized truck as a gift. How would you decide if the truck moves with constant speed, constant acceleration or changing acceleration?"⁸ Success on these tasks depends on the hypothetical-deductive reasoning and experimental skills. An example of such reasoning is: if the truck moves with constant acceleration, and if I determine its position every second, then the graph position versus time should be a parabola.

OSU FEH students had similar lab tasks. For example: "You have two unknown materials, how would you decide which one is a conductor and which one is an insulator." They had a similar type problem on a midterm exam. "You have two capacitors and the markings have been rubbed off. How can you decide which capacitor has a greater capacitance?" On this problem the average scores in the three sections were 83%, 80%, and 72%.

The majority of the students described an experiment whose outcome they would be able to predict based on their knowledge of capacitance. For example: "If you have a battery and a light bulb, charge both capacitors with the same battery. Then hook them to the light bulb one at a time, and record the duration that the bulb stays lit. As bulbs have same power ratings and both capacitors have the same potential, the current draw will be the same. As current is the flow of charge, the capacitor that lasts longer will have a greater stored charge. As capacitance equals charge divided by potential difference, and both have the same potential difference, the one with the greater charge will have the greater capacitance."

This response represents the most typical one – about 60% of the students described similar experiments. Some students were very creative. "First hook one capacitor to a voltage source and allow it to fully charge. Disconnect it. Hook the other up to the same source and allow it to fully charge. Disconnect it also. If you have a resistor that can be placed in water to heat it up. Use it. Get a cup of 3 oz of water at room temperature. Measure the temperature. Get the same cup with the same amount of water at

the same temperature and the same resistor. Hook capacitor 1 up to the resistor after placing resistor in water. Allow for full discharge. Measure the temperature of water. Repeat the same experiment with the other capacitor. Whichever cup had a greater increase in the temperature of water, received more energy and therefore had more capacitance because

$$E = \frac{1}{2} CV^2 \text{ and } V \text{ was the same.}''$$

Students were very successful on this task. One reason for this is that they performed similar tasks in lectures and labs, received plenty of feedback and knew exactly what was expected. We found, however, that a different decision-making task, if used without previous feedback, is very difficult for the students. "Indicate if you agree or disagree with the following statement by a friend and explain why you agree or disagree. 'Electrical conductors and non-conductors (also called insulators) have the same electric properties. Both a metal bar and a wooden rod resting on a pivot that rotates will be attracted to a charged object.'"

The average grades on this question for the three sections were 62 %, 68 %, and 65 %. However, closer examination at their responses indicated that these grades do not reflect the real situation. Students' responses were coded on a binary scale 0-1 if they...

- a) indicated that the statement itself was problematic;
- b) suggested one more experiments to disprove the statement;
- c) provided a theoretical explanation of the difference between the dielectrics and conductors.

Below are the results of coding (3 sections):

Code			
a)	0.29	0.30	0.29
b)	0.25	0.35	0.28
c)	0.61	0.72	0.61

The coding indicates that students mostly offered a theoretical explanation for the structure of the materials, and apparently the grader considered this sufficient. This example shows that such assignments require scoring rubrics for grading and some training of graders.

IV "Convincing" tasks

Students need to convince their friend that a physics concept or law makes sense⁹. These can be given as homework, recitation assignments

and exam questions. Below is a final exam question (OSU, 2002).

“A friend of yours in another physics class does not think that Kirchhoff’s voltage (loop) rule works. Describe in detail how you would convince your friend otherwise.”

Students mostly focused on describing an experiment that they would perform (about 50%), some described the why the rules work from a theoretical point of view (about 25%) and some used hypothetical-deductive reasoning – “if-then” logical argument using an experiment (about 20%). For example: “I would construct a simple circuit consisting of two batteries and two resistors all in series. I would then use Kirchhoff’s loop rule to find the potential difference between points A and B. If the rule works, then if I use a voltmeter to find then the actual voltage between A and B I will get the same results as in my calculations.” Or “I would show him a circuit of many loops and do some calculations. I would set up $I = I_1 + I_2$ and $12V - I_1R_1 - I_2R_2 = 0$ and $12V - I_1R_1 - I_3R_3 = 0$ and then take an ammeter and test what the voltages really are. This will show him.”

At the same time a reasonable number (about 15%) used the authority approach: “Tell him that the potential difference must be the same after it completes the circuit as it was starting out, so the sum of the voltage changes must be zero.”

Comparison of the grades and coding of this question revealed the need for a scoring rubric, otherwise a grader favors one approach to the task.

Conclusion

Assessment tasks described in this paper encourage students to focus on the development of skills useful in the real world: question asking and problem posing, reflection and self-assessment, decision-making and communication. Our experience shows that students can learn these skills only if regular feedback is provided. Problems with grading of the tasks can be avoided with the help of scoring rubrics and the training of the graders.

¹ Black, P. & Wiliam, D. (1998a). Assessment and Classroom Learning. *Assessment in Education*, 5 (1), 7-74.

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- ⁸ Suggested by S. Brahmia, Rutgers, 2001.
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