

# Assessment To Complement Research-Based Instruction In Upper-Level Physics Courses

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**Abstract.** Traditional upper-division physics courses tend to focus on summative assessment through quantitative and symbolic problem-solving examination questions. Reforming instruction suggests the need for assessment that matches the instructional strategies. In this paper, we describe assessment strategies implemented in two physics core courses, thermal physics and mathematical methods. Strategies include frequent formative assessment in the form of written ungraded quizzes as well as the inclusion of qualitative written problems on graded quizzes and exams. Examples of assessment items and student responses will be shown. In particular, we will show evidence that students at this level respond more positively to ‘pretests’ than one might expect, suggesting more expert-like epistemological expectations than is often the case in the introductory course.

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## INTRODUCTION

Assessment serves multiple purposes in instruction. For example, the NRC report *Knowing What Students Know* articulates three purposes for assessment: assessment to assist learning (often described as formative assessment), assessment of individual achievement (summative assessment), and assessment to evaluate programs [1]. In addition to these purposes, physics education researchers often use classroom assessments as part of their research methodology. The literature on assessment is vast; for this brief paper, we focus on a small number of widely-cited sources, particularly a review by Black and Wiliam [2] and a related summary [3]. Black and Wiliam observed that formative assessment has a positive impact on learning and that students benefit from the feedback that formative assessment can offer. This feedback can help students to develop the ability to self-assess and become more independent learners.

We describe assessment in the context of two upper-division courses for physics majors. Typically, upper-division courses tend to be even more traditional than lower-division courses, with course assessments that are purely summative and connected to student grades, with little explicit attention to informing instructors or students. Even less common is the use of assessment to evaluate the effectiveness of instruction. The assessments in such courses are typically restricted to symbolic and analytical problem solving in the form of homework problems from the course textbook and written examination problems. Black and Wiliam [3] make the following claims

(among others) about classroom assessment in precollege education:

*The tests used by teachers encourage rote and superficial learning even when teachers say they want to develop understanding; many teachers seem unaware of the inconsistency.”*

*“The giving of marks and the grading function are overemphasized, while the giving of useful advice and the learning function are underemphasized.”*

While these comments are not directed to the instruction in upper-division physics courses, they nevertheless are an accurate description of them.

As the PER community begins to perform research in upper-division courses and develop curricular materials and instructional strategies for these courses, there is a necessity for assessment strategies and items that touch upon all of the aspects of assessment. In particular, there is a great need for classroom-based assessment in upper-division courses that is formative and involves qualitative reasoning as well as more traditional quantitative skills.

## CONTEXT FOR WORK

This work has taken place in the context of two upper-division physics courses at California State University Fullerton, a large public comprehensive university serving a diverse student population. Both courses are core courses that are required of physics majors and taken by many physics minors.

The first course, *Thermal Physics*, is a core course required of physics majors. The course follows the hybrid ‘thermal physics’ approach that blends classical

thermodynamics and statistical physics, using a popular recent text [4]. It meets for two 75-minute blocks per week. The author has taught the course nine times, with enrollments between 6 and 19, and typically spends a significant portion of class time on small-group tutorial exercises, some of which have been described previously [5, 6].

The second course, *Math Methods*, is a physics core course required of physics majors and taken by most physics minors. The course is a prerequisite for most of the other physics core courses and is intended to assist students in developing the fluency with advanced mathematics that is expected in other upper-division physics courses. It uses a standard text [7] and covers topics including vector calculus, Fourier series, differential equations, and linear algebra. Like the Thermal Physics course, Math Methods is a small course (7 – 20 students) meeting twice a week in two 75 minute blocks that are nominally lecture periods but in practice used by the author as a mix of large- and small-group instruction.

The formal assessment strategies used in the target courses are described below. In addition to these strategies, the courses are designed to be highly interactive, with less-formal in-class formative assessment in the context of large- and small-group discussions, kinesthetic activities [8], and tutorial instruction. The author makes a great effort to produce a classroom environment that is supportive of open discussion and risk-taking.

*Ungraded quizzes.* Approximately once per week, students take an ungraded quiz. The ungraded quizzes are intended to serve as part of a formative assessment process as well as inform the author's research on student learning. The questions on these quizzes focus on material from past courses, material from recent lectures or reading, or material from past or upcoming tutorials. The quizzes are one or two pages and typically take ten to twenty minutes of class time. Although these quizzes are ungraded, students receive a small amount of participation credit.

*Graded quizzes.* In both courses, the first exam typically comes in the sixth or seventh week of instruction. After observing that many students had little sense of their course grade and had little idea of how to prepare for the exam, the author instituted short graded quizzes approximately one per two weeks. Each quiz is one page long and focuses on a single topic. The quizzes are closed-book, closed-notes and typically include a mix of quantitative and conceptual questions on a topic (See Figure 1).

*Traditional and modified homework.* Homework is collected approximately weekly and is graded. The homework includes a mix of traditional textbook problems and more qualitative questions, often coupled closely to the tutorial instruction in the course.

For an example of a homework exercise added after evaluation of a tutorial suggested a gap in student learning, see ref 5.

*Course examinations.* Course examination scores are the largest part of course grades. So that these measures match the goals of the instructional reforms, exams have been revised to include a mixture of standard symbolic manipulations and more qualitative and conceptual items. In addition to their use in assigning grades, student responses on selected examination items are used as research items to probe student understanding and/or to evaluate the effectiveness of instruction. An example of an assessment serving this purpose is shown in Figure 2 as well as in references 5 and 6.

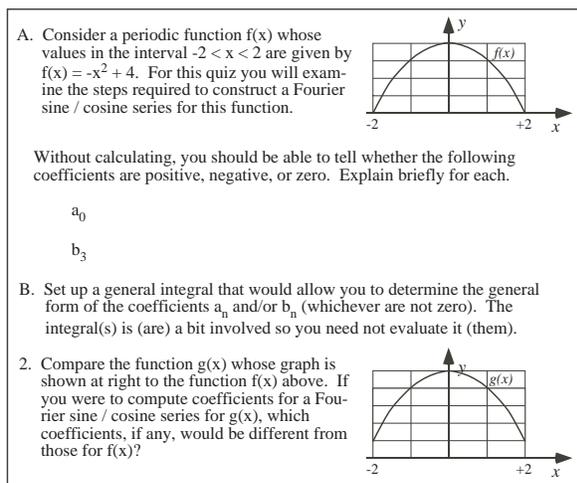
## REVISION OF SUMMATIVE ASSESSMENT ITEMS

One major focus of the author's work has been to develop and revise assessment items to incorporate more qualitative reasoning and a greater focus on conceptual understanding in addition to mathematical and quantitative skills. Often this process involves revising assessment items typical of standard courses and supplementing them with additional tasks that reward and support qualitative and conceptual reasoning. In this section, we describe an example (examples) of this process and show data of student responses to illustrate the value of this type of question.

Figure 1 shows a quiz given in the Math Methods course. The question is drawn from the portion of the course covering Fourier series (Chapter 7 in ref. 7). Whereas most standard homework and examination questions provide students with a function and ask them to determine coefficients for the sine and cosine functions, this problem asks that students do this but also adds some more conceptual questions to probe understanding of the ideas underlying the math. The function  $f(x) = -x^2 + 4$  is similar to those from the assigned homework but not identical.

As the problem is written, part B is the standard procedural question. In the interest of time, students are asked to set up integrals that would allow them to determine the relevant coefficients but not evaluate the integrals. While this task does not allow for a complete solution, most students at this level can compute integrals once they are properly constructed. Student responses for this part show that setting up the integrals is not too difficult for students. Nine of the fourteen students in the class set up correct integrals (with very minor typos at worst). Of the remaining five, all had an integral of the correct form, but made errors in either the limits of integration or the

periodicity of the function. In most cases, students either used the form of the integral for functions with period  $2\pi$  or left the limits and/or period as the unknown  $l$  rather than using the given function and graph to determine the period. Despite these errors, the student responses suggest that this procedural task is not excessively difficult for students.

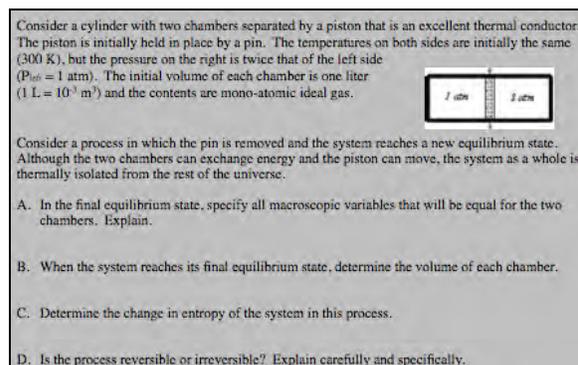


**FIGURE 1.** Quiz question with conceptual and more quantitative procedural questions.

The remaining parts of the quiz, on the other hand, were more difficult for students. The task labeled part A asked students to state without calculating whether the coefficients  $a_0$  (for the constant term) and  $b_3$  (for the third sine term) were positive, negative, or zero. The course text and lectures emphasized interpretation of  $a_0$  as the average value of the function (positive in this case), and using the even and odd behavior of functions to eliminate superfluous calculations (making all  $b_n$  zero in this case). Only three of the fourteen students answered correctly for both  $a_0$  and  $b_3$ . The answers revealed not only incorrect explanations but a general failure to make sense of the ideas underlying the procedure.

The question numbered 2 gives students a different function  $g(x)$  that is shifted upward, and asks students which of the coefficients would be different for  $g(x)$  compared to those for  $f(x)$ . As the new function differs only by addition of a constant shift, the only term that would change is  $a_0$ . Again, only three of the fourteen students answered correctly. (These were not the same three as for part B.) Student answers again revealed a lack of understanding of the underlying ideas. Most importantly, this response pattern suggests that the procedural question, however difficult it might seem to some students, is a relatively weak test of student understanding. Instructors may see students answering correctly but fail to recognize

that students have largely memorized or practiced a procedure without understanding the meaning of what they are doing. While such phenomena are common in introductory courses, the prejudice of some instructors is that physics majors in upper-division courses naturally develop understanding from mastering the math. These data suggest otherwise.



**FIGURE 2.** An exam question adapted from a traditional textbook [9].

Throughout this project, we have sought to adapt other traditional questions by adding conceptually-oriented tasks. A second example of this effort is illustrated in Figure 2, showing a course examination question from the Thermal Physics course. This question is an adaptation of a homework problem from a traditional textbook, which asks students to compute a change in entropy and interpret the result. The revised version inserts intermediate tasks, first asking students to state which thermodynamic variables are equal in the final equilibrium state. (Previous research shows that this task is difficult for students [10].)

## SURVEY OF STUDENT OPINION OF UNGRADED QUIZZES

As noted, the ungraded quizzes served as a research tool as well as a means of informing the instructor about student understanding. However, an equally important purpose of formative assessment is to inform students of their understanding and provide opportunities for learning and reflection. In order to determine the extent to which students valued the ungraded quizzes and assess whether students were using them as opportunities for self-assessment, we devised a brief survey. The survey had five questions, most including a five-point scale ranging from strongly negative to strongly positive, with ample room for explanation. The survey was given to students immediately after the final exam in the Thermal Physics course and they were told that it was optional and would not be read until after course

grades were complete; all 13 students who took the final elected to complete the survey. Two of the questions that asked for agree/disagree responses pertained to the ungraded quizzes. These questions and the student responses are shown below:

What is the impact, if any, of the ungraded quizzes on your learning of course material?

*9 of 13 positive or strong positive, 4 neutral*

What is the impact, if any, of ungraded quizzes on your level of confidence or happiness?

*6 of 13 positive or strong positive, 4 neutral, 1 negative, 1 'both positive and negative.'*

Students were positive about the impact of the quizzes on their learning and positive or neutral about the affective issues. The written responses and explanations given by students were revealing.

*Strong positive. ...If I saw the ungraded quiz and got a low [?] ... I knew I had to study more.*

*I thought I had some understanding and the quiz always threw me a curveball ... I would always be like 'Wait, you can ask that?'*

An important goal of upper-division courses is that students become more independent learners. Many students made similar statements, in which they stated that difficulties on the ungraded quizzes suggested to them the need for additional study. It should be noted that this may or may not have resulted in any changes in behavior; one student responded, honestly:

*It meant that I should probably do a review....but I can't say that I always did a review!*

Another student gave a highly nuanced answer:

*Strong positive. Having ungraded quizzes is an interesting experience and good one because it encourages the mind to free thinking and tries to nurture intuition in the student.*

*Negative and positive. Yes, I answered twice because both are true. They were negative because of the heavily entrenched reaction to not doing well on a quiz but they were ultimately positive because it showed a place to go and a correction to improper thinking.*

*After I got past the sinking feeling that had been hammered into me from several years of school, it generally left me with a curiosity about the material to come.*

The literature on assessment suggests the tension between the perceived judgment of summative assessment and the learning role of formative assessment, this student's response reflects that tension, reinforced by prior school experiences. Another student noted an aspect of the class that she felt made formative assessment worthwhile:

*Regardless of students' feelings' they are a good tool and deserve an objective perspective. Feeling inadequate, on tutorials or tests or otherwise, sucks, but shouldn't be a factor in something that*

*provides information. We know what we know coming in, and you don't punish us for our gaps, so there should be nothing to be upset about.*

The fact that this student perceived that ungraded quiz results are used for guidance and not to punish students again mirrors the literature. As previously noted, the instructor took great pains to create a classroom environment conducive to discussion.

While most of the responses to the survey were similar to those quoted above, two of the responses requested that answers to ungraded quizzes be provided, and two others suggested that the quizzes had little impact.

## SUMMARY

The experience with the courses described in this paper reinforces the value and need for rethinking assessment in upper-division courses, particularly those using research-based curriculum. Student responses to quiz and examination questions illustrate the fact that even with upper-division courses, students can succeed on procedural quantitative problems and still struggle with the underlying concepts. Student responses to the end-of-course survey suggest that most of these students value sense-making opportunities and may use ungraded quizzes as the impetus for self-study and reflection.

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