Final Report for Teagle Assessment Project

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Goals and objectives assessed

For this project, our department focused on the following objective from our department’s learning goals document:

A.4: A student should be able to articulate expectations for, and justify reasonableness of, problem solutions, including both dimensional analysis and numerical values.

The full list of learning goals and objectives is attached to this report as an appendix. The specific objective above is part of our top-level goal number 4:

Students will develop and exhibit the learning, problem-solving, communication, and laboratory skills enumerated below.

Strategy for achieving this objective

Our overall strategy for achieving this objective is that each instructor models this strategy repeatedly in class lectures, laboratories, and in written solutions to problem sets. Different instructors differ in how much explicit attention they give to articulating this as a goal in their classes, but we all model it extensively for the students.

Assessment activities

To assess this objective directly, several faculty members teaching courses in the Physics and Astrophysics major sequences incorporated specific questions into homework assignments or exams, asking students to evaluate the reasonableness of their solutions to particular problems. Because of the diversity of different kinds of questions asked in different courses, we did not use a rubric to evaluate the student responses; instead, each faculty member reported his/her own scoring (or other judgment) of how students performed on those questions. Courses including this sort of assessment were Physics 5, 7, and 111 (respectively a first-year course, a sophomore-level course, and a junior seminar), and Astro 16 (the first Astro-specific course in the Astrophysics major, often taken by sophomores).
Findings

We found that students (including first-semester, first-year students in Physics 5) were generally fairly skilled at doing this, as long as it was modeled regularly by the instructors in presenting material in class. This is our main conclusion, but there are some interesting nuances as well.

Because of the different ways that instructors chose to implement this assessment in their courses, we were able to gain some insight into the extent to which students had (or in many cases had not) internalized this skill as part of their problem-solving approach in general. In some cases, students were asked explicitly, “Is this answer reasonable?” (or a variant thereof). For example, in Physics 5, 80–90% were able to do this correctly in questions on both the midterm and the final exam, employing at least one correct check of reasonableness. A similar percentage of students in Astro 16 could do this as well. In both cases, these students were asked explicitly to employ a test of reasonableness. Similarly, students in Physics 7 and Physics 111 were able to do this well when asked directly (as the Astro 16 and Phys 5 students were). However, these students also had some assigned problems where they could use a reasonableness check to help solve the problems (and where such a check would have made the problem easier to solve), but they were not told to do so. In this situation, a smaller percentage of them (50–60% in Phys 7) did so explicitly, even though such checks were always presented as part of problem-solving strategy and checking in class. The data collected by the instructor in Phys 111 were more anecdotal than those from Phys 7, but they confirmed this overall pattern: roughly half of the students can do this when asked, but do not automatically do so, even when it would be to their advantage.

Using the results

This apparent division—that students apparently possess a valuable problem-solving skill but often do not employ it unless told to do so explicitly on a given problem—presents an interesting dilemma. Is this disconnect something that we can address with pedagogy that is specifically targeted at getting students to employ this problem-solving technique? Or is it something that is one aspect of a larger truth, namely that novices approach problems differently than experts do? (And by extension, that many of our students, especially in the first two years of their undergraduate careers, are still very much novices.) The idea of novice vs. expert learners has a long history in theories of education in general, and in physics
education research in particular, but it is a relatively new idea to me, and I suspect to many members of our department. Looking at a description of features of novice vs. expert learners in STEM fields, a number of qualities would appear to apply to this situation. For example, “Novices tend to … work backwards (the answer defines the way to solve or approach the problem), while experts work forward, *checking logic and answers as they go*”\(^1\) (emphasis added).

Given this, it is not obvious to us that these data point toward changes *targeted toward this particular objective* that we should make to our curriculum or our teaching. We have found that even first-semester students can develop and apply this skill, given enough practice, though it is clear that students need repeated reminders that this is a valuable problem-solving technique that they should continue to apply in a variety of contexts. What it does point to, however, is the importance of continuing to be aware of students’ overall development as problem solvers (and learners of physics in general), and helping them to develop the habits of mind that will eventually transform them into expert learners. For my own teaching, this strengthens my inclination to continue to emphasize problem solving as a process and to talk to students about my own thinking in solving a problem, reinforcing the importance of metacognition in their learning.

Appendix: Learning Goals for Physics and Astronomy majors at Swarthmore College

Top-level Goals for Major Program

I. Students will show mastery of the physics and astronomy content goals enumerated in the individual course syllabi for the required courses for the major. Students will be able to solve homework and especially exam problems related to particular physical laws or principles, e.g. Gauss’s law or conservation laws.

II. Students will gain an understanding of the nature and breadth of contemporary open questions in physics and/or astronomy.

III. Students will experience the scientific process, and the nature of the interplay of theory and experiment, in contemporary physics and astronomy. One way that students can gain this experience is by doing research.

IV. Students will develop and exhibit the learning, problem-solving, communication, and laboratory skills enumerated below.

Specific skills

A. Problem-solving skills:

A student should be able to . . .

1. translate a physical description into a mathematical equation, and conversely, explain the physical meaning of the mathematics.
2. represent the key elements of a physical situation with a sketch.
3. choose, apply, and justify appropriate problem-solving techniques in novel contexts. For all students these techniques include approximations and symmetries, and as students advance, their techniques will come to include series expansions, multivariable integration, differential equations, and linear algebra.
4. articulate expectations for, and justify reasonableness of, problem solutions, including both dimensional analysis and numerical values.
5. devise an algorithm for solving a problem numerically, and translate that algorithm into a working computer program.

B. Learning skills:

A student should be able to . . .

1. articulate the fundamental ideas from each chapter, section, and/or lecture.
2. see the physical relationships in the course as both coherent and broadly applicable, evidenced by being able to use these physical relationships to solve a range of problems, including ones in novel contexts.
3. demonstrate awareness of what he/she doesn't understand, evidenced by asking sophisticated, specific questions, articulating where they experience difficulty, and taking actions to move beyond that difficulty.
4. work productively in a group to solve problems, including asking questions and giving constructive feedback to others.
5. build on the material learned in earlier courses on the same topics and make connections to material on nominally different topics.

C. Communication skills:

A student should be able to . . .

1. write clearly and persuasively about an experiment, calculation, or observation, following the conventions of scientific writing.
2. design and give a clear presentation, with a well-supported argument, aimed at the appropriate level for a variety of different audiences.
3. effectively and supportively critique their own and other students’ arguments and presentations.

D. Laboratory skills:

A student should be able to . . .

1. explain the connection between a measurement of a natural phenomenon and the experimental apparatus and tasks of a laboratory exercise. The explanation will exhibit an understanding of the theory behind the experiment, an understanding of the experimental equipment, and an assessment of the accuracy of the technique.
2. devise a strategy for analyzing quantitative data to obtain a desired result, including characterizing the precision, accuracy, and robustness of the result (i.e. understanding how sensitive the results are to various types of errors, both measurement and fitting errors, and identifying the appropriate way to fit the data that takes error into account).
3. troubleshoot an experiment, i.e., identify the sources of something producing an unexpected result or not working at all.
4. use a software environment (Mathematica, MATLAB, etc.) to do fairly sophisticated numerical calculations and/or data analysis, as well as graphing and fitting data.
5. analyze experimental data to determine best-fit parameters and reasonable error estimates on those parameters from the data, and be able to judge whether or not a given relation is an acceptable fit to the data given the uncertainties.
6. reflect on results of an experiment and discuss whether the experiment was successful.

(last revision: May 2012)