

What Else (Besides the Syllabus) Should Students Learn in Introductory Physics?

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Abstract. We have surveyed what various groups of instructors and students think students should learn in introductory physics. We started with a Delphi Study based on interviews with experts, then developed orthogonal responses to "what should we teach non-physics majors besides the current syllabus topics?" AAPT attendees, atomic researchers, and PERC08 attendees were asked for their selections. All instructors rated "sense-making of the answer" very highly and expert problem solving highly. PERers favored epistemology over problem solving, and atomic researchers "physics comes from a few principles". Students at three colleges had preferences anti-aligned with their teachers, preferring more modern topics, and the relationship of physics to everyday life and also to society (the only choice with instructor agreement), but not problem solving or sense-making. Conclusion #1: we must show students how old physics is relevant to their world. Conclusion #2: significant course reform must start by reaching consensus on what to teach and how to hold students' interest (then discuss techniques to teach it).

Keywords: Delphi study, instructional goals, introductory physics

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INTRODUCTION

In times past, introductory physics was a lecture-recitation course, and discussions of course reform were limited to changing syllabus topics and better integrating the laboratories into the course. The development of tests of conceptual understanding [1] disclosed limitations of conventional instruction [2]. These were accompanied by many new instructional developments [3] and web-based activities to enhance learning (<http://phet.colorado.edu>, WebAssign.net, MasteringPhysics.com). Course reform discussions now often concern which of these teaching techniques to adopt.

Our view is that course reform and particularly adoption of new instructional techniques should start with agreed-upon instructional goals, rather than teaching techniques. This is imperative because learning goals under contemporary discussion include cognitive abilities [4], scientific abilities [5] and *habits of mind* (e.g., "demonstrate problem solving skills by initially developing a qualitative description of the problem") as well as syllabus topics [6].

PROCEDURE AND SAMPLE

We wanted to elicit what non-topical learning goals for introductory physics today's teachers are ready to adopt. We used a Delphi study approach [7],

initiated by asking about 20 successful instructors – mostly from the PER or American Association of Physics Teachers (AAPT) communities – to suggest such goals in their own words. From their responses we distilled 12 alternatives. Then we polled successive groups of instructors, using the question:

"Due to a change in the academic calendar, you have 20% more time to teach the calculus-based introductory course to non-physics majors, and the syllabus has not been expanded. What learning will you seek to add or emphasize with this extra time?"

The respondents (except at PERC) were given a brief description of the topics and allowed to select two. Slight revisions of the alternatives, led to the following set of selections that elicited stable responses, grouped into the four categories listed below:

1- Course Content

- Wider content: e.g gyroscopes, optics, quantum mechanics, modern physics...
- Discovery or Traditional Labs

2- Instructional Themes

- Scientific method, hypothesis and experimental test
- Physics is constructed from a few ideas that can be expressed mathematically.
- Epistemology: how do I know, derivations?

3- Problem Solving

- Vocabulary of Domain
- Concepts: "Be Newtonian thinkers"

- Problem Solving: understand, plan the solution starting with concepts
- Problem Solving: make sense of an answer (includes estimation) using units, special or limiting cases, symmetry, etc.

4- Relation to the Outside World

- Write/Present scientific argument either in oral or written formats
- Science in news and society, to read science news critically, e.g. be able to examine a New York Times article for sense and consistency.
- Physics applied to everyday life/things, to understand how objects around you work. (For example, the damped spring with two levers that closes the door smoothly behind you).

We queried different classes of instructors (see Table 1): *educators* at AAPT meetings, *atomic researchers* at a Gordon Research Conference and *education researchers* at a physics education meeting. These three groups agreed on some topics, but also disagreed substantially on others. We also asked several groups of students what they wanted to learn. Students in different institutions were in reasonable accord, but their preferences generally anti-correlated with their instructors’.

PREFERENCES

The percentage of positive responses given by each of the three groups of instructors (educators, atomic and educational researchers) for each of the alternatives are plotted together in figure 1, and, in figure 2 the preferences of students and instructors

Table 1. Description of the participants and number of votes.

Subsample	N
<i>Educators</i> :	268
- at AAPT meetings	
- at US Military Academy	
<i>Atomic Researchers</i> at 2007 Gordon Conference	219
<i>Education Researchers</i> at 2008 PERC	221
All Instructors	708
Calculus-based MIT students 2007, 2008	269
Calculus-based College de Paul students	78
Oregon State	215
All Students	562

(average of educators, atomic researchers and education researchers) are compared. The dashed, black and gray portion of the bars corresponds to the 95% confidence intervals for proportions calculated using the normal approximation. The scientific method and vocabulary of subject domain were unpopular (average under 2%) with the three groups of instructors and with students as well, and are not included in the figures.

Similarities and differences between instructor groups

The most striking fact about instructor preferences is that there is no “must do” selection. Sense-making of an answer was the instructors’ top choice (only 17%). All instructor groups showed about average preference for both laboratories (10%) and understanding science in news and society (10%), and a disdain for wider content (4%).

The most notable difference among instructors was on problem solving - the combination of vocabulary, Newtonian thinking and plan-set up. Educators selected problem solving (excluding sense-making) at 39%, more than atomic researchers (16%) and even more than education researchers (7%). For education researchers epistemology (17%) generally applies to the construction of individual students’ knowledge (e.g. whether the student thinks problem solutions are obtained by applying memorized formulae rather than thinking about the concepts), and a good fraction of epistemological effort is aimed at better problem solving [8]. Counting most of the epistemology responses as problem solving responses puts Education Researchers near the average of all instructors in this category. Education researchers thought “scientific argument” (15%) was more important than the other two instructor groups (average of 5.5%). Atomic researchers rated “physics from a few ideas” (17%) as their top selection while educators were less enthusiastic (6%).

Similarities and differences between instructors and students.

There are substantial differences between students and instructor preferences (Figure 2). Wider content was students’ top preference but instructors’ lowest (19% vs. 4%). The relation of physics to everyday life-things was students’ second preference but the instructors’ second lowest (15% vs. 6%). On the other hand, students had no interest (3%) in sense-making, the instructors’ top selection (17%). Students had little interest in scientific argument (2%) which instructors thought merited significant attention (9%). Students and instructors agreed on priorities of 5 of the 10 options - physics from a few ideas,

epistemology, Newtonian thinking, plan - set up, and understanding of science in news and society. However the differences on the other selections were so marked that the correlation between students' and teachers' preference is - 0.4.

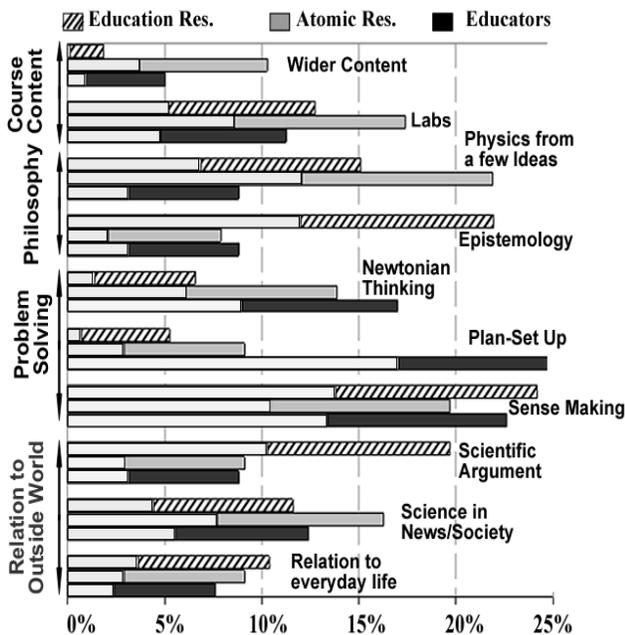


Figure 1. Percentage of each instructor group choosing each topic as important addition to syllabus.

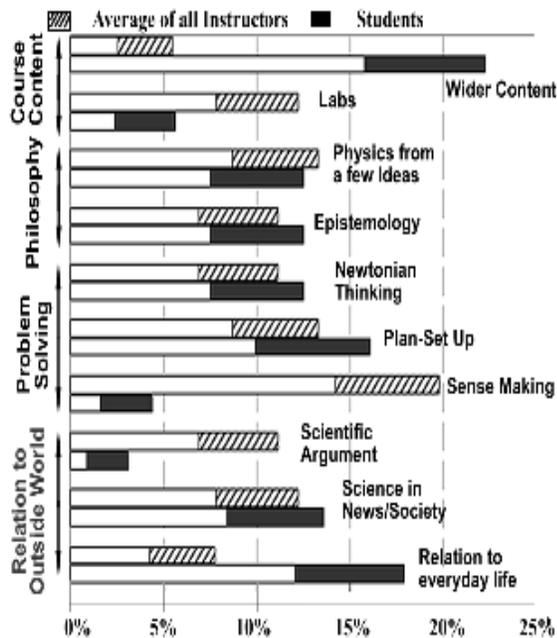


Figure 2. Percentage of instructors and students choosing each topic as important

PRIORITIZING COURSE REFORM GOALS

We set out to determine a set of prioritized goals to guide future discussions of course and pedagogical reform. The lack of any strong and universal preference together with the disparity between different groups of instructors suggests that each university or college must prioritize its own goals (and that this may not be easy). The disparity between instructors and students demands addressing students' priorities in this process. Even given instructor and student consensus, reform has other major constraints: finite instruction time, concerns of the physics department, requirements of departments needing the course as a prerequisite, and the college's overall goals. We now discuss possible reforms in light of these constraints, taking the questions in order.

Wider Content: Rather than attempting to cram extra material in, a better approach may be to add real world and societal relevance to existing topics so students find revitalized interest in familiar topics.

Physics from a few ideas: is a natural part of any effort to give students a coherent overview of course material that textbooks (and lectures, by association) have recently been criticized for lacking [9]. We feel that communicating an overview should be part of any significant course reorganization, and need not consume much additional time.

The "Problem Solving" categories except Sense Making had high priority among instructors and students. Both physicists and members of departments for whom physics is a service course extol introductory physics as a place for students to learn transferable problem solving skills. Unfortunately, most introductory physics students are closer to novice than expert problem solvers and cannot approach or solve physics problems appropriately or represent them qualitatively [10]. Instilling expert problem solving seems necessary and important. However, this will take a significant course time and development of new materials since there is no accepted instrument for measuring expert problem solving proficiency, and research shows that over 90% of end of chapter problems in even "reform" textbooks unintentionally encourage solution using novice methods [11]. Even reformed courses generally *decrease* the expertness of students' problem solving attitudes, and few of the methods developed by the physics education research community for helping students become more expert problem solvers are in widespread use.

Sense-making has the highest priority of any single selection among instructors, but the second lowest by students. It is possible, however, that some part of the

significant student response to “relation to everyday life” is relevant to this category. Sense making is systematically addressed in only a few courses that force students to use a problem-solving rubric [12]. The learning of sense-making requires new problems and revised grading schemes. It is a good place to try to connect students’ intuition with their formal problem solving, but it will require significant additional time.

Scientific Argument: When introductory courses use reformed instructional practices in which students work together to solve problems, oral presentation of each group’s solution can be integrated with only a modest commitment of time.

Science in Society and Everyday Life: Basing problems on relevant examples should increase student interest and would seem not to take a lot of effort [13].

SUMMARY AND FUTURE

Our most important finding is the anti-correlation of students’ attitudes with those of their instructors. The instructors seem to be saying, “We are going to make you into experts,” and the students seem to be replying, “Before we commit to this much hard work, tell us how physics connects to society’s problems and to the world around us, and teach us interesting new things we didn’t learn in high school.”

Overall, both students and instructors want students to become more expert problem solvers (although students don’t see the value of making sense of their answers). This is a laudable objective that will require not only significant course time, but also collaboration between physics education researchers and educators to develop easily transferrable instructional and organizational principles and development of good instruments to measure problem solving ability.

Our results, like any exploratory study, raise new questions for the future. Are there other groups of instructors, and how do they compare with those studied here? How do student attitudes change over the semester? (Preliminary results from College of DePaul indicate they lose interest in studying more topics and become much more interested in problem solving - presumably reflecting concern with grades.)

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