

Physics Graduate Students' Attitudes and Approaches to Problem Solving

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Abstract. Students' attitudes and approaches to problem solving in physics can profoundly influence their motivation to learn and their development of expertise. We administered an Attitudes and Approaches to Problem Solving (AAPS) survey to physics graduate students and analyzed their responses about problem solving in their own graduate level courses vs. problem solving in introductory physics. The physics graduate students' responses to the survey questions were also compared with those of introductory students and physics faculty. Survey responses suggest that graduate students' attitudes about graduate-level problem solving sometimes has similar patterns to introductory-level problem solving by introductory students.

INTRODUCTION

Students' attitudes and approaches towards learning can have a significant impact on what students actually learn [1, 2, 3]. In essence, it is impossible to become a true physics expert without a simultaneous evolution of expert-like attitudes about the knowledge and learning in physics. If students think that physics is a collection of disconnected facts and formulas rather than see the coherent structure of the knowledge in physics, they are unlikely to feel the need for organizing their knowledge hierarchically. Similarly, if students believe that only a few smart people can do physics, the teacher is the authority and the students' task in a physics course is to take notes, memorize content and reproduce it on the exam (and then forget it), they are unlikely to make an effort to synthesize and analyze what is taught, ask questions about how concepts fit together or how they can extend their knowledge beyond what is taught.

The Maryland Physics Expectation Survey (MPEX) was developed to explore students' attitudes and expectations related to physics [1]. When the survey was administered before and after instruction in various introductory physics courses, it was found that students' attitudes about physics after instruction deteriorated compared to their expectations before taking introductory physics. Very few carefully designed courses and curricula have shown major improvements in students' expectations after an introductory physics course [4, 5].

Colorado Learning Attitudes about Science Survey (CLASS) is another survey which is similar to the MPEX survey and explores students' attitudes about physics [2, 3]. The analysis of CLASS data yields qualitatively similar results to those obtained using the MPEX

survey. Moreover, when introductory physics students were asked to answer the survey questions twice, once providing the answers from their perspective and then from the perspective of their professors, introductory students' responses to many questions were very different from their perspective compared to what they claimed would be their professors' perspective [3].

Cummings et al. [5, 6] developed an Attitudes towards Problem Solving Survey (APSS) which is partially based on the MPEX survey. The APSS survey has 20 questions and examines students' attitudes towards problem solving [6]. The survey has been administered to students before and after instruction at different types of institutions.

Here, we discuss responses of physics graduate students on the Attitudes and Approaches to Problem Solving (AAPS) survey, a modified version of APSS survey [6] that we developed which includes additional questions. We explore how graduate students differ in their attitudes and approaches while they solve graduate level problems versus introductory level problems. The attitudes and approaches of graduate students on the AAPS survey were compared to those of introductory physics and astronomy students and to physics faculty.

DEVELOPMENT AND ADMINISTRATION OF SURVEY

In order to develop the AAPS survey, we selected 16 questions from the APSS survey [6] and modified some questions for clarity based upon in-depth interviews with five introductory physics students and discussions with several faculty. We also developed 17 additional questions, many of which focused on approaches individu-

als take to problem solving, and modified them based upon the feedback from introductory students during interviews and discussions with physics faculty. The reason introductory physics students and faculty were sought for this purpose is that we hypothesized that the responses of these two groups would be the most disparate and would provide the most diverse set of feedback for improving the preliminary survey. Some of the themes in the additional questions are related to the use of diagrams and scratch work in problem solving, use of "gut" feeling vs. using physics principles to answer conceptual questions, reflection on one's solution after solving a problem to learn from it, giving up on a problem after 10 minutes, preference for numerical vs. symbolic problems and enjoying solving challenging physics problems.

The interviews with five students from a first-semester algebra-based class were helpful in ensuring that the questions were interpreted clearly by the students. Of approximately 40 students responding to the invitation for paid interviews, five were selected. Since we wanted all students to be able to interpret the problems, two students were randomly chosen for interview from those who scored above 70% and three students were chosen who obtained below 70% on their first midterm exam. The survey questions were administered to all interviewed students in the form of statements that they could agree or disagree with on a scale of 1 (strongly agree) to 5 (strongly disagree) with 3 signifying a neutral response. During the individual interviews, students were also asked to solve some physics problems using a think-aloud protocol to gauge whether what they answered in the survey questions about their attitudes and approaches to problem solving were consistent with the attitudes and approaches actually displayed during problem solving.

The final version of the AAPS survey was first administered anonymously to 16 physics graduate students (GSs) enrolled in a graduate level course. Discussions with the graduate students after they took the survey showed that all of them interpreted that the survey was asking about problem solving in their own graduate courses and that they would have answered the questions differently if they were asked about their attitudes and approaches to solving introductory physics problems. Then, we administered the survey a second time to 24 graduate students (there was overlap between the first cohort of 16 graduate students and this cohort) with the questions explicitly asking them to answer each question about their attitudes and approaches to introductory physics problem solving. Due to lack of class time, this second round of survey was administered online. We had individual discussions with 4 graduate students about the reasoning for their AAPS survey responses and invited all 24 graduate students who had answered the questions online to write a few sentences explaining their reasoning for selected survey questions

online. We explicitly asked them to explain their reasoning when they answered the survey questions about problem solving in the graduate level courses and separately for introductory physics. Ten graduate students (out of 24 who took the survey online) provided written reasonings for their responses. The survey was also administered to two sections of the first-semester algebra-based physics course with 209 students, two sections of the second-semester algebra-based physics course with 188 students, one first-semester calculus-based course section with 100 students and a second-semester calculus-based course section with 44 students. In addition, the survey was given to 31 students in an introductory astronomy course. Finally, the survey was given to 12 physics faculty who had taught introductory physics recently. We also discussed faculty responses to selected questions individually with some of them.

We do not differentiate between "agree" and "strongly agree" in interpreting the data. Similarly, "disagree" and "strongly disagree" were combined. A favorable response refers to either "agree" or "disagree" based upon which one was favored by a majority of faculty. Below, we present some of our findings. In all the graphs, we separately show the average percentage of favorable and unfavorable responses for each question for each group.

Graduate Students' Expertise at Graduate Level

Comparison of average graduate students' responses for graduate level problem solving with those of physics faculty suggests that graduate students are still developing expertise in problem solving at the graduate level. For example, in response to question (6), all of the physics faculty noted that while solving physics problems they could often tell when their work and/or answer is wrong even without external resources but only approximately 50% of the graduate students could do so while solving graduate level problems and approximately 80% of the graduate students could do so for introductory level problem solving. Moreover, the survey response of the graduate students to this question for graduate level problems is similar to that of the introductory physics students for introductory level problems. Such similarity suggests that while graduate students' attitudes are more expert-like for solving introductory problems, that is not the case when solving graduate level problems. Figure 1 shows that, in response to question (11) about whether equations need not be intuitive in order to be used and whether they routinely use equations even if they are non-intuitive, graduate students' responses while solving introductory physics problems were similar to those of faculty and approximately 75% disagreed with the statements (favorable response). However, when answering graduate level problems, only slightly more than 50% of the graduate students noted that equations must be un-

derstood in an intuitive sense before being used. Individual discussions suggest that the graduate students felt that sometimes the equations encountered in the graduate courses are too abstract and they do not have sufficient time to make sense of them and ensure that they have built an intuition about them. The following sam-

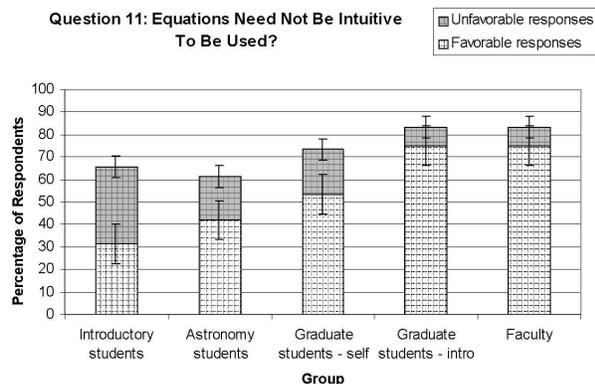


FIGURE 1. Histogram showing favorable (disagree) and unfavorable (agree) responses for survey question (11).

ple responses from some graduate students reflect their sentiments:

- "...you just cannot understand everything. So it's ok to deal with the homework first. But I really feel bad when I do plug and chuck (sic)."
- "As an intro student I had the point of view that the equations are right so my intuition must be wrong. I used equations to get the answer whether it made sense at first or not, but I trained my intuition with every such result. I had more faith in the physics that is taught to me than the physics intuition I acquired just by observation. As a graduate student, one is already used to the unintuitive results being the correct one, they have by then become intuitive."
- "I am often still presented with equations to calculate something without enough motivation to understand the process, even at the graduate level, and being able to use the equation and accept that you'll understand it later is often necessary. For students' first course in physics, this is more the rule than the exception at some level..."
- "I remember physics via the equations, so I try my best to always understand the meaning. But if I can't, I fall back on "this is the equation, use it"."

The responses of the introductory students suggest that they are even more likely than graduate students to use equations to calculate answers even if they are non-intuitive (see Figure 1). This finding is consistent with the prior results that suggest that many introductory students view physics problem solving as an exercise in finding the relevant equations rather than focusing on

why a particular principle may be applicable and building an intuition about a class of physics problems [1, 2].

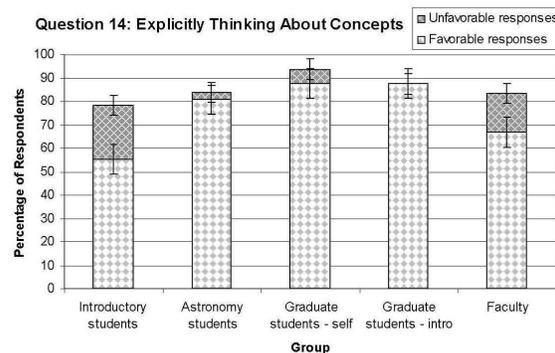


FIGURE 2. Histogram showing favorable (agree) and unfavorable (disagree) responses for survey question (14).

Unexpected Trends Require Careful Analysis

Figure 2 shows that, in response to question (14) regarding whether they always explicitly think about concepts that underlie the problems when solving physics problems, close to 90% of the graduate students agreed (favorable) that they do so both in the context of introductory and graduate level problem solving. However, only approximately 65% and 55% of the physics faculty and introductory physics students agreed, respectively. The non-monotonicity of responses in Figure 2 going from the introductory students to faculty may seem surprising at first, but individual discussions suggest that some faculty do not always explicitly think about the concepts that underlie the problem because the concepts have become obvious to them due to their vast experience. They are able to invoke the relevant physics principles "automatically" when solving a problem without making a conscious effort. In contrast, prior research suggests that introductory physics students often do not explicitly think about the relevant concepts because they often consider physics as consisting of disconnected facts and formulas and associate physics problem solving as a task requiring hunting for the relevant formulas without performing a conceptual analysis and planning of the problem solution [1, 2]. Thus, the reasoning behind the less favorable responses of faculty to question (14) is generally very different from the reasonings behind the introductory physics students' responses.

Expertise of Introductory Physics Students

Survey responses suggest that the introductory physics students have less expert-like attitudes and approaches to solving introductory physics problems than other groups. For example, survey responses suggest that manipulation of symbols rather than numbers increases the difficulty of

a problem for many introductory physics students. Question (30) asked whether symbolic problems were more difficult than identical problems with numerical answers and question (31) asked if individuals preferred to solve a problem with a numerical answer symbolically first and only plug in the numbers at the very end. In response to question (30), only approximately 35% of the introductory physics students disagreed with the statement (favorable response) that it is more difficult to solve a problem symbolically, and in response to question (31), only 45% agreed with the statement (favorable response) that they prefer to solve the problem symbolically first and only plug in the numbers at the very end. Similarly, Figure 3 shows that for question (31), the responses of graduate students for both introductory and graduate level problem solving are comparable to physics faculty but introductory students' responses are very different. Individual discussions with some introductory students suggest that they have difficulty keeping track of the variables they are solving for if there are several symbols involved, which motivates them to substitute numbers at the beginning of the solutions.

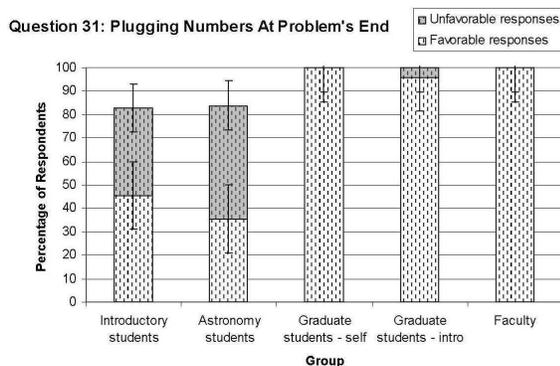


FIGURE 3. Histogram showing favorable (agree) and unfavorable (disagree) responses for survey question (31).

Reflection After Solving a Problem

Problem solving is often a missed learning opportunity because, in order to learn from problem solving, one must reflect upon the problem solution [7]. The survey responses suggest a general lack of reflection by individuals in each group after solving problems. In response to question (20), only approximately 55% of the graduate students (for both introductory and advanced level problems) noted that, after they solve homework problems, they reflect, i.e., take time to learn from the solution. The percentage of faculty members who routinely reflect after problem solving is close to 75% which may be lower than expected. Individual discussions suggest that, for introductory level problems, both physics faculty and graduate students felt that they monitor their thought processes while solving the problems since the

problems are relatively simple. Therefore, reflection at the end of problem solving is not required. In discussions and/or written explanations, some faculty and graduate students explained that they do reflect after solving a problem when the problem turns out to be challenging. Moreover, while solving graduate level homework problems, some graduate students pointed to the lack of time for why they do not take the time to reflect after solving problems. Following are examples of GSs responses:

- *"If I have enough time, then I would like to reflect and learn from the problem solution after I struggle with it for a long time and then finally solve it successfully."*
- *"If the solution or the problem is interesting, then I would take time to reflect and learn from it. This usually happens in more challenging problems."*
- *"To be honest, I didn't do this when I was in college. But now I realized it's helpful."*

Only 25% of introductory physics students noted that they reflect and learn from their problem solutions. These findings suggest that instructors should consider giving students explicit incentive to reflect after they solve physics problems [7].

SUMMARY

Comparison of survey responses about graduate students' problem solving in introductory physics with introductory students' responses suggests that graduate students generally have more expert-like attitudes about introductory physics problem solving than introductory students. Survey responses also suggest that graduate students' attitudes about graduate-level problem solving sometimes has similar trends to introductory problem solving by introductory students. Survey responses, discussions and written explanations suggest that time-constraints sometimes keep graduate students from doing things they realize are valuable.

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