

Characterizing the Epistemological Development of Physics Majors

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Abstract. Differences between novice and expert physics students have frequently been reported, yet students' development through intermediate stages has seldom been described. In this study, we characterize undergraduate physics majors' epistemological sophistication at various levels of degree progress. A cross-section of physics majors was surveyed with the Colorado Learning Attitudes about Science Survey. Beginning physics majors are significantly more expert-like than non-physics majors in introductory physics courses; furthermore, this high level of sophistication is constant over the first three years of the physics degree program, with increases at the senior and graduate levels. Based on longitudinal data on a subset of students, we observe negligible average shift in students' responses over periods of up to two years. We discuss implications for how and why physics students' epistemological sophistication develops, including a possible connection between CLASS survey response and self-identification as a physicist.

Keywords: epistemology, physics majors, beliefs, development

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INTRODUCTION

The field of science education has a rich research tradition of comparing the skills and ways of thinking of experts to those of novices. Physics education researchers have been especially interested in making these comparisons in the areas of problem solving¹⁻³ and beliefs about the nature of physics knowledge⁴⁻⁷. Studies involving novice-expert comparisons have focused on people at opposite ends of the educational spectrum – students in introductory physics courses and advanced graduate students or faculty. Understanding these differences is important in helping students become more expert-like, but recognizing differences alone may leave out a description of if or how students develop expertise or expert-like views. In this study, we aim to further our understanding of this development process by examining physics majors at intermediate stages of expertise.

We focus on one aspect of students' development – their beliefs about the nature of physics knowledge and how to learn physics. We use the term epistemological sophistication to describe the level of similarity between these beliefs and those commonly held by physicists. These beliefs are thought to be an important factor in what and how students choose to study, and increased sophistication is a hoped-for, but

often-unrealized course outcome⁷. Several survey instruments have been designed to assess beliefs about the nature of science and learning⁴⁻⁸.

STUDY DESIGN

As a measure of students' epistemological sophistication, we administered the Colorado Learning Attitudes about Science Survey (CLASS)⁵ during the 2004-2005 and 2005-2006 academic years at the University of California, San Diego to 533 students. Students were surveyed in lower- and upper-division courses for physics majors, several sections of the first course in the introductory physics sequence for engineering students⁹ and a first year graduate course (see Table 1). The courses for physics majors are small (n~30) and are uniformly taught in a traditional lecture format. The physics department recommends a four-year program of courses; we surveyed courses from each year that are part of the required core sequence. Thus, students are likely to take these courses in the order recommended by the department. We used a rotating panel study design, surveying courses repeatedly, so that students in different stages of the program were surveyed in successive quarters. We thereby obtained cross-sectional and short-term longitudinal data.

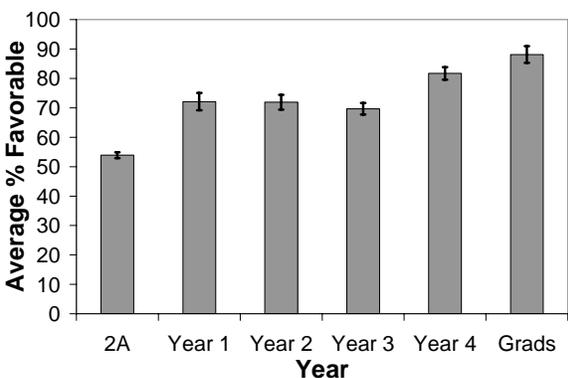


FIGURE 1. Average percent favorable responses to CLASS survey by year in degree program. 2A is an introductory physics course for engineering students, and grads are first year graduate students. Error bars indicate standard error of the mean.

Although many surveys are currently available for measuring students' epistemological stances, we find CLASS the most suitable for a study of physics students at different stages of degree progress. The CLASS items do not address the students' expectations of their performance in any specific course. Instead, the CLASS was designed with the intention to elicit student thinking about a broader context of physics. Although it is likely that students think of their experiences in their current courses while responding to the survey, the wording allows students taking many physics courses to respond more generally about their physics experiences and makes it easier to compare students across courses. In addition, when calibrating the survey, faculty respond to the items in the same frame as the students (not "How would you like your students to answer?"). We find this framing useful in trying to make inferences about how novice students develop more expert-like views.

The surveys were administered in lecture, and were completed by the students in a paper and pencil format. There are, of course, advantages and disadvantages in using this method. In yielding lecture time, instructors give implicit (or in some cases explicit) encouragement to participate in the study and to take the survey seriously. We also find that students who choose to volunteer are very likely to complete the entire survey. However, lecture time is at a premium, so some students are rushed to address all 42 survey items, and some instructors are reluctant to give up any lecture time. Only students who attended lecture were invited to participate in the study, and no course credit was awarded for participation.

The students took the survey during last two weeks of instruction, before the final exams. The only pre-test we administered was in the first course of the degree program (4A) during the winter quarter 2006.

We decided to administer the survey only once per course in order to avoid effects of sampling the students too often (in the quarter system, a student could be asked to take the survey six times in a single academic year with both pre- and post-testing). We opted for post-tests over pre-tests because we expect students to be more honest about their current behavior than about what they expect their behavior to be.

Surveys were evaluated by the number of items on which students agreed or strongly agreed with the expert (favorable) response, leading to an overall percent favorable score for each student. Students were grouped by year in the degree program, and ANOVA was used to detect differences between years¹⁰. With the exception of the introductory course for engineering students, students who had declared majors outside of physics were excluded from the analysis. For the cross-sectional analysis, if a student completed the survey in multiple courses, only the student's first survey was included, so that all included samples are independent. The Games-Howell test was used for post-hoc comparisons between years¹¹. The longitudinal component of the study consisted of the students who responded to the survey in more than one quarter. Only students' first and second surveys were included in the analysis. A two-tailed, paired samples t-test was used for making comparisons. Differences at the $p < 0.05$ level were considered to be significant.

TABLE 1. Group Summary

Group (Courses Included)	N	Average % Favorable	Standard Deviation
2A	378	53.9	19.3
Year 1 (4A, 4B)	33	72.1	16.9
Year 2 (4C, 4D, 4E)	29	71.9	13.6
Year 3 (100A, 100C & 130A)	56	69.7	14.7
Year 4 (130B)	16	81.7	8.5
Grads (200A)	7	88.1	7.5

RESULTS

Figure 1 shows the average number of favorable responses from students in each year of the physics major, the introductory course for engineering students (2A), and the graduate course (200A). Year in the program is based on the department's suggested sequence of courses. Table 1 shows the number of

respondents in each course. An analysis of variance indicates statistically significant differences between the average number of favorable responses for these groups, $F(5,513)=26.17$, $p<0.001$. Games-Howell post-hoc testing, summarized in Table 2, indicates that 2A students are statistically different from all years of physics majors and graduate students. Students in Years 1, 2 and 3 are not significantly different from each other, nor are students in Years 1, 2 and 4. However, Years 3 and 4 are statistically different. Additionally, the graduate students are statistically different from all years except Year 4. The graduate students are the most epistemologically sophisticated as measured by CLASS.

TABLE 2. Difference in Average % Favorable, with Post-Hoc Test Results (an * indicates statistical significance at the 0.05 level)

Group i	Group j	Difference in Average % Favorable (i-j)	P
2A	Year 1	-6.56*	<.001
	Year 2	-7.17*	<.001
	Year 3	-5.87*	<.001
	Year 4	-9.84*	<.001
	Grads	-12.30*	<.001
Year 1	Year 2	-0.62	0.998
	Year 3	0.68	0.994
	Year 4	-3.28	0.141
	Grads	-5.74*	0.009
Year 2	Year 3	1.3	0.868
	Year 4	-2.66	0.239
	Grads	-5.13*	0.016
Year 3	Year 4	-3.96*	0.005
	Grads	-6.43*	0.002
Year 4	Grads	-2.46	0.422

Of the 141 physics majors surveyed, 50 responded to the survey more than once, generally within one or two quarters of their initial response. The longitudinal data on this subset of students allows us to directly monitor changes in students' survey responses over time. The average difference between the percent of favorable responses on students' second and first surveys is -0.1%, with a standard deviation of 1.4%. A two-tailed, paired sample t-test shows no statistically significant difference between the percent of favorable responses in students' first and second surveys, $t(50)=0.075$, $p=0.941$. A similar result was found among students in Year 3 only (students transitioning from 100A to 100C). Unfortunately, the data set does not include students transitioning between Year 3 and Year 4.

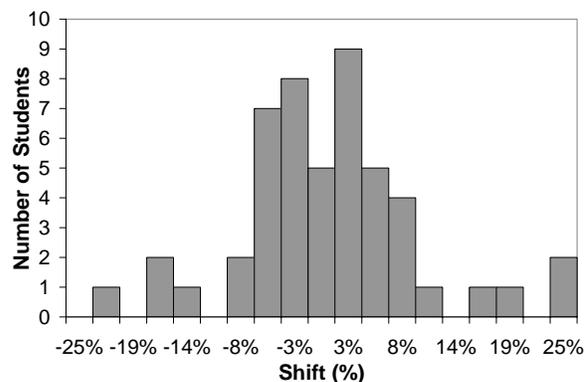


FIGURE 2. Histogram of difference in percent of favorable responses between second and first course in which student responded to survey. The mean difference is -0.1%, with a standard deviation of 1.4%.

DISCUSSION

Based on the data in Figure 1, undergraduate physics majors represent an intermediate stage between novice and expert. All years of physics majors are more expert-like than 2A students, the first three years of majors are less expert-like than graduate students, and students in the fourth year of the major are comparable to graduate students. Interestingly, however, this transition does not seem to be smooth and continuous. Rather, the cross-sectional data indicate a substantial difference between 2A and years 1-3, and no statistical difference between years 1-3. The longitudinal data in Figure 2 indicate that for students in years 1-3, individual students' overall responses to CLASS do not change over time. We thus infer that physics majors begin the degree program with a relatively high degree of physics epistemological sophistication (compared to their non-physics major peers) that does not change during the first three years of the program. As a result, we suggest that the expert-like views assessed by CLASS are, to a significant extent, an inherent, preexisting characteristic of students who choose to be physics majors, rather than a characteristic that is learned or acquired during the degree program. We note there are differences at the fourth year and graduate level.

Although Figure 1 indicates that physics majors have relatively sophisticated ideas about the nature of physics knowledge and how to learn physics when they enter the university, the source of this sophistication is unknown. Does it come from high school physics courses? Perhaps, but many engineering students also study physics in high school. Another possible source is extracurricular investigation of physics. Students who are interested in physics enough to consider it as a major may be more likely to have exposure to popular physics media,

which would address many of the nature of physics survey items. Although we do not have data to directly address this hypothesis, it is consistent with the survey data showing that physics majors have more personal interest in physics than engineering students¹².

Although we do not observe an increase in epistemological sophistication in the first three years of study, students in the fourth year are more sophisticated. In light of data suggesting that introductory students can reliably identify expert responses to survey items and distinguish those responses from their own⁵, it is possible that this increase in survey score at the senior year results from enculturation and changes in identity. Students in the senior year are typically preparing for their careers after graduation, and many apply for graduate school. During the application process, students identify themselves as potential physicists and seek acceptance into the community of physicists. It is possible that during this process, students' embrace views they recognize as accepted by the physics community.

CONCLUSION

In this study, we find that physics majors come to the university with beliefs about physics that are relatively expert-like. Overall, these beliefs are consistent throughout most of the undergraduate program, with an increase for students in the final year of study. Graduate students have more expert-like beliefs than undergraduates, and physics majors have more expert-like beliefs than engineering students enrolled in introductory physics courses. These results suggest that physics majors' epistemological sophistication, as measured by CLASS, is a preexisting trait rather than something learned at the university.

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9. There are few physics majors in the introductory physics course for engineering students; most physics majors enroll in a separate sequence.
10. In our data the groups have unequal variances. ANOVA assumes that groups are normally distributed with equal variances, though it is robust upon departures from these conditions. We confirmed the results of ANOVA with Welch's test, which identifies differences between groups and does not require equal variances. In all cases, Welch's test agreed with ANOVA.
11. Games-Howell was chosen because it does not require equal sample sizes or variances.
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