Characterizing the epistemological development of physics majors

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Students in introductory physics courses are likely to have views about physics that differ from those of experts. However, students who continue to study physics eventually become experts themselves. Presumably these students either possess or develop more expertlike views. To investigate this process, the views of introductory physics students majoring in physics are compared with the views of introductory physics students majoring in engineering. In addition, the views of physics majors are assessed at various stages of degree progress. The Colorado learning attitudes about science survey is used to evaluate students' views about physics, and students' overall survey scores and responses to individual survey items are analyzed. Beginning physics majors are significantly more expertlike than nonmajors in introductory physics courses, and this high level of sophistication is consistent for most of undergraduate study.

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I. INTRODUCTION

Comparisons between experts and novices are widely used for understanding various aspects of student learning, including problem solving skills[1–4] and views about physics.[5,6] Such comparisons show that introductory physics students have views about physics that can be quite different from the views of physicists. It has been demonstrated that students in introductory courses can develop more expertlike views when discussion of epistemological issues is explicit and integrated into the curriculum,[5,7] but they more typically become less expertlike during introductory courses. Many of these studies have used survey instruments such as the Colorado learning attitudes about science survey (CLASS) to compare introductory students and physics faculty populations. These endpoint comparisons do not explore the views of students with intermediate levels of experience in physics. We compare the relative expertise (as determined by CLASS score) of physics majors at various stages of degree progress and nonmajors. By identifying students' views at different academic stages, it is hoped that some insight can be gained as to when and how expertlike views about physics are achieved. Specifically, we compare the extent to which students' views change to become more expertlike and the extent to which pre-existing expertlike views selected for during undergraduate study.

A preliminary clarification of terminology is needed. The terms attitudes, beliefs, and views have all been used in physics education research to describe students' ideas about physics knowledge (its nature and origin), learning physics, and solving physics problems. These ideas are related to the amount of effort students are willing to put forth in learning physics, their motivations for engaging in certain learning and problem solving activities, and their personal interest in physics. In psychology, the term attitude is used to describe a construct that represents a person's like or dislike for something[8] (i.e., "I enjoy solving physics problems"—CLASS item 25). Similarly, the term belief is used to describe a psychological state in which a person is convinced of the truth of a proposition[9] (i.e., "knowledge in physics consists of many disconnected topics"—CLASS item 6). Attitudes and beliefs are fundamentally connected, and the CLASS probes both. In the CLASS, attitudes and beliefs are convolved with students' expectations ("I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations"—CLASS item 13). Therefore, no attempt will be made to distinguish between them in this study. The term "views" will be used to encompass attitudes, beliefs, and expectations about physics knowledge and learning physics.

II. STUDY DESIGN

As a measure of students' views about physics, we administered the CLASS (Ref. 10) during the 2004–2005 and 2005–2006 academic years at the University of California, San Diego (UCSD) to 519 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 students, and a first year graduate course (see Table I). The number of year 4 and graduate student participants is small, and we are therefore cautious to avoid drawing conclusions from these data. Nevertheless, they are reported in order to provide context for interpreting the other undergraduate data. The courses in this study that are aimed at physics majors are small ($n \sim 30$) and are uniformly taught in a traditional lecture format. The physics department recommends a four-year program,[11] and students generally take courses in the order recommended by the department. We repeatedly surveyed courses from each year that are part of the required core sequence, using a rotating panel study design,[12] so that students in different stages of the program were surveyed in successive quarters. We thereby obtained cross-sectional and short-term longitudinal data. Cells in Table I that are of the same color indicate a cohort of students that was sampled multiple times.

Although many surveys are currently available for measuring students' views,[6,13–15] we find CLASS the most suit-

TABLE I. (Color) Courses surveyed, with information about topic covered, which year students typically take course, number of respondents for each year, average and standard deviation of the percentage of favorable responses for each year, and academic quarter during which each course was surveyed. For the physics major courses (all except 2A), same-colored cells indicate a cohort of students who may have been surveyed multiple times. Cell key: upper: number of surveys included in cross-sectional analysis and lower: number of respondents (number of enrollees).

	Year	Fall 2004	Winter 2005	Spring 2005	Fall 2005	Winter 2006	Spring 2006
2A (Mechanics for Engineers	Eng.	**378**					
4A (Newtonian Mechanics)	1		**14** 14*(30)*			**15** 15*(19)* Pre & Post	
4B (Fluids, Waves & Thermo.)				**2** 9*(32)*			**2** 7*(17)*
4C (E&M)	2	**12** 12*(23)*					
4D (Optics, Special Relativity)			**7** 14*(24)*				
4E (Quantum Physics)				**2** 8*(25)*			**8** 21*(25)*
100A (E&M)	3	**40** 40*(52)*					
100B (E&M)							
100C (E&M Elective)				**1** 5*(22)*			**10** 15*(29)*
130A (Quantum Mechanics)				**5** 21*(62)*			
130B (Quantum Mechanics)	4	**16** 16*(27)*					
200A (Graduate Mechanics)	Grad	**7** 7*(15)*					

Cell Key:

 # Surveys Included in Cross-Sectional Analysis
Respondents *(# Enrollment)*

able for a study of physics students at different stages of degree progress. Although CLASS items do address students' expectations about learning, the survey's authors tried to avoid addressing expectations about course performance, making it more convenient to compare students across courses.[10] Additionally, when calibrating the survey, faculty were asked to respond to the items based on their own views (not "how would you like your students to answer?"), a framing that is useful for determining the relative expertise of students' views.

The surveys were administered in lecture and were completed by the students in a paper and pencil format. Only students who attended lecture were invited to participate in the study, and no course credit was awarded for participation. Most students who chose to participate completed the entire survey.

The students took the survey during the last 2 weeks of instruction before the final exams. In order to obtain responses before students began the degree program, one pretest was administered 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 6 times in a single academic year with both pretesting and post-testing.) We opted to do these *in situ* post-tests rather than pretests because we wanted students to report their current behavior rather than what they expect their behavior to be.

The students' responses to the CLASS were analyzed by evaluating the number of student responses that were aligned with the expert (favorable) response, leading to an overall percent favorable score for each student. In this type of analysis, the strength of the response (i.e., disagree vs strongly disagree) is not considered. Students were grouped by year in the degree program and analysis of variance (ANOVA) was used to detect differences between years.[12]

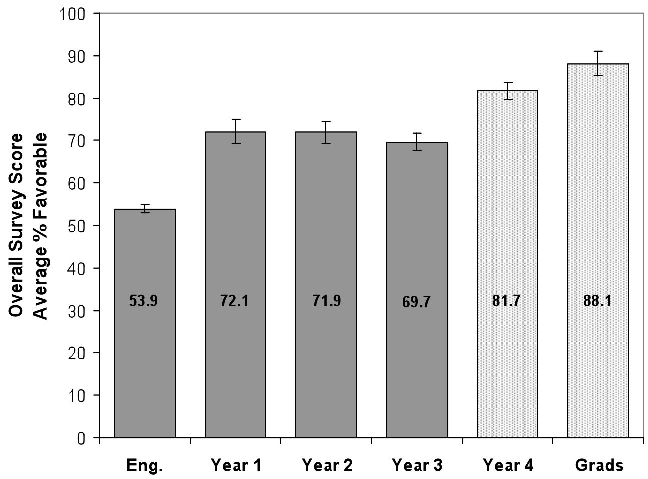

FIG. 1. Average percentage of favorable responses. Error bars indicate the standard deviation of the mean. Year 4 and grad data are grayed out to indicate a small number of responses for these groups.

With the exception of the introductory course for engineering students, students who had declared majors outside 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 years.[16] The Games-Howell test is similar to a t test but reduces the probability of falsely rejecting the null hypothesis for multiple comparisons between groups and is appropriate when groups have unequal variances. The longitudinal component of the study consisted of the students who responded to the survey in more than one quarter. Students' first and last surveys were compared using two-tailed paired samples t testing. For statistical tests, differences at the $p<0.05$ level were considered to be significant. In addition to overall survey score, specific views were probed by analyzing the responses to individual items.

III. RESULTS

A. Overall score

An analysis of overall survey score shows that physics majors at all years of study report more expertlike views than engineering students, and that the average favorability of views reported by physics majors is consistent for the first three years of undergraduate study. Figure 1 shows the average number of favorable responses from students in each year of the physics major, the introductory course for engineering students (eng), and the graduate course (grad). Our classification of "year" is based on the department's suggested timing and sequence of courses for physics majors. Table I shows the courses included in each year, as well as the number of respondents. An analysis of variance indicates statistically significant differences between the average number of favorable responses of the eng and year 1–3 groups, $F(3495)=28.19, p<0.001$. Games-Howell posthoc tests were conducted among the eng and year 1–3 groups; as discussed earlier, the year 4 and grad groups were excluded from this comparison due to small numbers. Results of the posthoc tests, summarized in Table II, indicate that there are no statistically significant differences between students in years 1–3. Unsurprisingly, the physics majors indicated a higher personal interest in physics than the engineering students. However, this higher interest only accounts for part of the difference in overall survey score. To investigate this issue, we conducted a second analysis of the students' responses excluding items in the personal interest category.[10] As shown in Table II, average responses on nonpersonal interest items follow the same pattern as the overall responses: physics majors report more expertlike views than engineering students, and views of physics majors are at a consistent level of expertise during the first three years of study.

Of the 148 physics majors surveyed, 51 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 allow changes in students' responses to be monitored over time. The average difference between the percent of favorable responses on students' first and second surveys is 0.1%, with a standard error of the mean equal to 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, $t(50)=0.075, p=0.941$. Figure 2 shows a histogram of the percent shift in the number of favorable responses for students who completed the survey multiple times during this study. The figure is color coded to show students' shifts over within-year transitions and between-year transitions. The distribution of each of these transitions is closely centered on a 0% shift.

TABLE II. Detailed Games-Howell test results for overall survey score and overall score excluding personal interest category. Difference in average percent (%) favorable, with posthoc test results [the asterisk (*) indicates statistical significance at the 0.05 level].

		Overall score		Excluding personal interest	
Group i	Group j	Difference in average % favorable (i−j)	p	Difference in average % favorable (i−j)	p
Eng	Year 1	−18.2*	<0.001	−21.5	<0.001
	Year 2	−19.9*	<0.001	−24.3	<0.001
	Year 3	−16.3*	<0.001	−20.6	<0.001
Year 1	Year 2	−1.7	0.971	−2.8	0.929
	Year 3	1.9	0.950	0.9	0.997
Year 2	Year 3	3.6	0.674	3.6	0.777

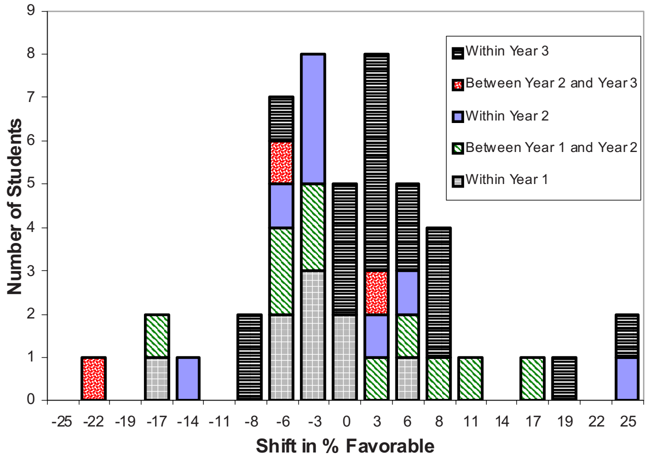

FIG. 2. (Color) Histogram of the percent shift in favorable scores for multiply surveyed students. Shift calculated using first and second surveys.

These longitudinal data indicate that for multiply-surveyed students in years 1–3, most individual respondents' overall CLASS scores are stable over time, with ~70% of respondents changing their total favorability by fewer than ±2 survey items. Considering both the cross-sectional and longitudinal data, we infer that physics majors begin the degree program with views that are relatively expertlike (compared to their nonphysics major peers) and that those views generally do not change during the first three years of the program. Furthermore, if we divide the year 1 students into two groups—those who took the CLASS as a pretest at the beginning of 4A and those who took the CLASS for the first time as a post-test in either 4A or 4B—the averages of these two groups are 71% (standard error=5%) and 73% (standard error=4%), respectively. This result indicates that entering physics majors' views are as expertlike as those of majors who have taken one or two university-level physics courses. We suggest that the expertlike views assessed by CLASS are a preexisting characteristic of students who choose to be physics majors rather than a characteristic that is learned or acquired during the degree program.

B. Analysis of specific items

In addition to evaluating the students' overall CLASS score, we looked at individual items to determine how specific views differ among the different years. In considering individual items, we evaluate the percent of students that responded favorably. Figure 3 shows the favorable response rate for selected survey items.

The survey item showing the largest range of responses across years is item 8 ("when I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values"). The favorability rate of all undergraduate years is less than 60%, while all the graduate students gave a favorable response. The unfavorable responses of year 1 and 2 students are striking because it suggests that students in the first two years of undergraduate study find the plug-and-chug strategy to be productive in solving physics problems. The increase in favorable responses among year 3 and 4 students is consistent with the more complex nature of upper-division coursework and as-

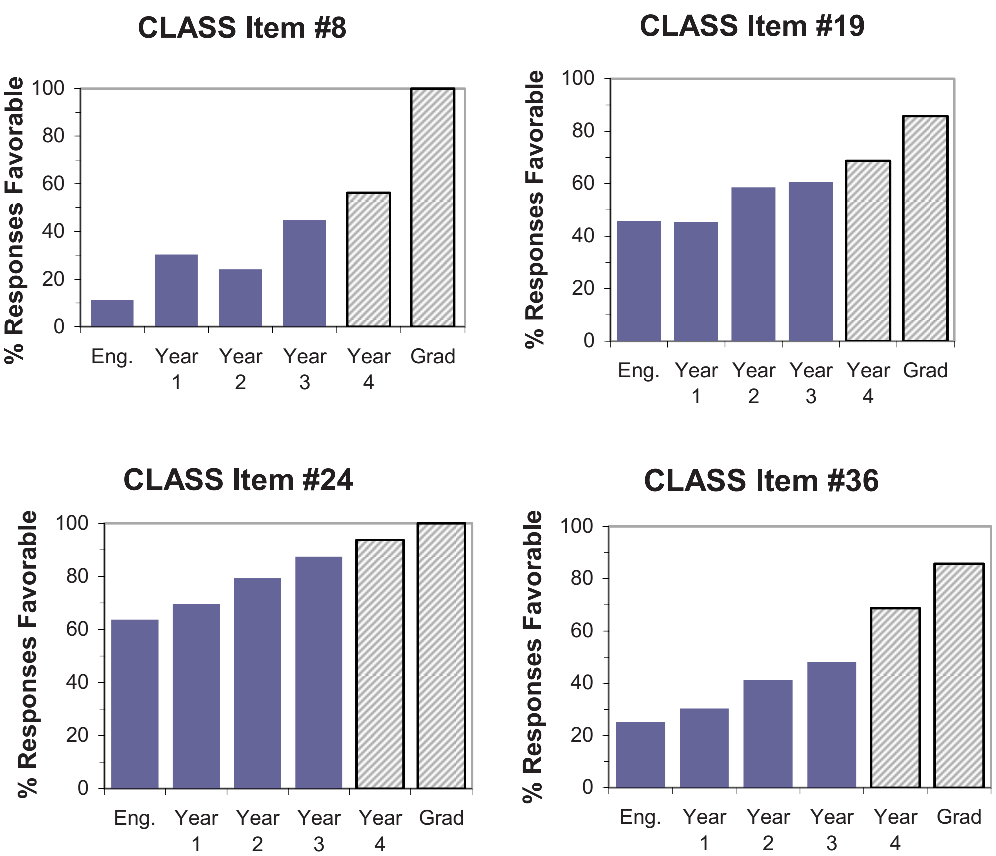

FIG. 3. (Color) Distributions of favorable responses for selected survey items.

signments. However, we are cautious not to overinterpret the response to a single item.

Several individual survey items related to sense making and problem solving demonstrate a trend of increasing favorability during undergraduate study. Two of these items include items 24 ("in physics, it is important for me to make sense out of formulas before I can use them correctly") and 36 ("there are times I solve a physics problem more than one way to help my understanding"). Both of these items address sense making activities for solving problems, and both items are in the sense making and effort category defined by researchers at the University of Colorado. Another item that shows a steady progression of increased favorability within the physics major is item 19 ("to understand physics I discuss it with friends and other students"). Again, this item seems to be related to sense-making activities (although it is not part of the sense making and effort category nor any other CLASS category). A trend of increasing favorability in a single item might be attributed to statistical variation, but a similar trend among several related items is more convincing. These trends suggest that students' views about role of sense making in problem solving may become more expertlike as students accumulate experience studying physics.

IV. DISCUSSION

The cross-sectional CLASS data clearly show that physics majors' overall views are more expertlike than the views of engineering students. This difference cannot be fully explained by physics majors' greater personal interest in physics. However, because the cross-sectional data are a snapshot in time across different students, it cannot clearly resolve how the overall views of individual physics majors change as students gain more experience in the major. The longitudinal data do track individual students and indicate that the overall views of most individual students are stable over short time scales in years 1–3. Taken together, the cross-sectional and longitudinal data indicate that many physics majors have relatively expertlike views when they begin undergraduate study of physics, and this expertise is maintained through year 3.

However, the longitudinal data do not include students moving from year 3 to year 4 or year 4 to graduate school, or follow students throughout their undergraduate career. Additionally, there is a small number of year 4 and graduate student participants in the cross-sectional data, making it difficult to draw reliable conclusions from those data. The cross-sectional data from year 4 and grad students are *consistent* with an increase in the favorability of students' views occurring near the end of undergraduate studies and between undergraduate and graduate studies but do not clearly resolve what happens beyond year 3. The increase in the overall score may be a sampling artifact, or students' views may actually change during this time. If the effect is real, we can imagine several possible causes. Students at this stage may be embracing beliefs they know to be accepted by the community of practicing physicists. This suggestion is informed by the finding that even students who are in the beginning of undergraduate study can accurately identify expertlike survey responses.[17] Year 4 students are finishing their undergraduate program and deciding if and where they are going to apply for graduate school. This process involves deciding whether they want to pursue a career in physics as well as convincing recommenders and admission committees that they are desirable candidates. Additionally, many senior-level undergraduates begin to participate in research projects. It seems reasonable that students at this level will begin to self-identify as physicists and embrace beliefs that are consistent with that identity. Alternatively, it is possible that individual students' views do not change, but that only students with the most expertlike views pursue physics through year 4 or go on to graduate school. The graduate students in this study were not undergraduates at UCSD, which additionally complicates comparison between the undergraduate and graduate respondents in this study. Additional data would be required to determine how students' views change as they finish a major in physics and begin graduate study.

The similar sophistication of entering physics majors and students in the first three years of study suggests that view-based self-selection plays a role at the beginning of the physics degree program. It was not observed that students with views that are largely misaligned with those of physics professors began a major in physics (thereby shifting the average to a lower favorability in the first year), nor was it obvious that students left the physics major because their views were misaligned with physics professors (thereby shifting the average to a higher favorability in later years). It is worth noting that the students involved in this study have chosen to enroll in introductory physics courses designed specifically for physics majors rather than the introductory sequence for engineering students. Students electing to take the sequence for majors are likely to have a strong commitment to the program and may be more resilient to selection pressures than students who "try out" the major in a more general introductory program. As a consequence, our results probably underestimate the degree of "view-based selection."

Students' survey responses show that physics majors enter the university with relatively expertlike views about physics compared to their peers in the engineering majors. Although it is not surprising that physics majors indicate a stronger personal interest in physics than engineering students, a more general difference in views is somewhat unexpected given that engineering students and physics majors often have very similar academic experiences with science.

Why is it, then, that incoming physics majors have more expertlike views about physics than engineering students? We suggest a couple of possibilities. First, a physics degree may be more attractive to students with more expertlike views. To many students, it is not obvious how a physics degree translates into a postbaccalaureate job, in contrast to engineering degrees. This is reflected in the fact that most physics undergraduates plan to pursue graduate degrees.[18] Without this employment incentive, it seems reasonable that students with less expertlike views, who do not appreciate the interconnected elegant nature of physics or have a strong personal interest in physics, would be less likely to pursue a physics degree.

Second, students who have enough interest in physics to declare a physics major may be more likely to have extracurricular experiences with physics (i.e., popular science media, science museums, after-school clubs, etc.), where expertlike views could be developed. Another possibility is that this result reflects a cultural influence. Students who grow up in families and/or communities whose views are aligned with those of the physics community may be more likely to choose a physics major. The results of this study suggest a need for more research on the early development of students' views about physics and the effects that extracurricular activities have on these views.

Of course, this study suggests other questions. What shapes students' views about physics before they get to college? What are the implications for how we educate physics majors? What happens to the development of physics majors if we try to explicitly teach expertlike views? Is there a limited pool of potential physics majors consisting of students whose views are largely in agreement with physics professors before coming to the university? Can physics departments recruit and retain students whose views differ from experts, and, if so, how can we help them develop expertlike views?

Finally, although UCSD has a fairly traditional physics degree program, we recognize that physics programs vary across institutions, and it is expected that different trends may be seen across different physics departments. Multi-institutional comparative studies would address questions about the effects of different physics degree programs on the development of expertlike views about physics.

V. CONCLUSION

In this study, we find that physics majors come to the university with views about physics that are relatively expertlike. Overall, these views are consistent throughout most of the undergraduate program. These results suggest that expertlike views about physics, as measured by CLASS, are largely a pre-existing trait of students who choose to be a physics major rather than something developed at the university. Furthermore, survey results provide little evidence suggesting that students leave the major for reasons related to their views. The factors shaping students' views about physics before they enter the university have not been established and are an important line of investigation.

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[1] C. Singh, When physical intuition fails, Am. J. Phys. **70**, 1103 (2002).

[2] R. J. Dufresne, W. J. Gerace, P. T. Hardiman, and J. P. Mestre, Constraining Novices to Perform Expertlike Problem Analyses: Effects on Schema Acquisition, J. Learn. Sci. **2**, 307 (1992).

[3] B. Sherin, Common sense clarified: The role of intuitive knowledge in physics problem solving, J. Res. Sci. Teach. **43**, 535 (2006).

[4] L. Hsu, E. Brewe, T. M. Foster, and K. A. Harper, Resource Letter RPS-1: Research in problem solving, Am. J. Phys. **72**, 1147 (2004).

[5] A. Elby, Helping physics students learn how to learn, Am. J. Phys. **69**, S54 (2001).

[6] E. F. Redish, J. M. Saul, and R. N. Steinberg, Student expectations in introductory physics, Am. J. Phys. **66**, 212 (1998).

[7] D. Hammer and A. Elby, Tapping Epistemological Resources for Learning Physics, J. Learn. Sci. **12**, 53 (2003).

[8] C. G. Jung, *Psychological Types* (Princeton University Press, Princeton, NJ, 1921).

[9] D. G. Myers, *Psychology* (Worth, New York, 2004).

[10] W. K. Adams, K. K. Perkins, N. S. Podolefsky, M. Dubson, N. D. Finkelstein, and C. E. Wieman, New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey, Phys. Rev. ST Phys. Educ. Res. **2**, 010101 (2006).

[11] L. C. McDermott and E. F. Redish, Resource Letter: PER-1: Physics Education Research, Am. J. Phys. **67**, 755 (1999).

[12] B. M. King and E. W. Minium, *Statistical Reasoning in Psychology and Education*, 4th ed. (Wiley, Hoboken, NJ, 2003).

[13] A. Elby, http://www2.physics.umd/edu/~elby/EBAPS/idea.htm, 2004.

[14] A. Elby, Another reason that physics students learn by rote, Am. J. Phys. **67**, S52 (1999).

[15] I. Halloun, http://cresmet.asu.edu/prods/vass.shtml, 2006.

[16] H. Sahai and M. I. Ageel, *The Analysis of Variance: Fixed, Random, and Mixed Models* (Birkhäuser, Boston, 2000).

[17] K. E. Gray, W. K. Adams, C. E. Wieman, and K. K. Perkins, Students know what physicists believe, but they don't agree: A study using the CLASS survey, Phys. Rev. ST Phys. Educ. Res. **4**, 020106 (2008).

[18] P. J. Mulvey and S. Nicholson, *Physics and Astronomy Senior Report: Class of 2003* (American Institute of Physics, College Park, MD, 2006).