Students know what physicists believe, but they don't agree: A study using the CLASS survey

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ABSTRACT

We measured what students perceive physicists to believe about physics and solving physics problems, and how those perceptions differ from the students' personal beliefs. In this study, we used a modified version of the Colorado Learning Attitudes about Science Survey (CLASS) which asked students to respond to each statement with both their personal belief and the response they thought a physicist would give. Students from three different types of university introductory physics courses were studied. Students who have not yet taken physics in college have a surprisingly accurate idea of what physicists' believe about physics, no matter what their high school background and what physics courses they choose to take in college. These ideas are largely unaffected by their college physics instruction. In contrast, students' personal beliefs about physics differ with varying high school physics backgrounds and college physics courses in which they enroll, and these beliefs are affected by college physics instruction. Women have a larger difference between their reported personal beliefs and their perceptions of physicists' beliefs than do men.

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INTRODUCTION AND BACKGROUND

While great inroads have been made to understand students' ideas about physics content in order to improve student learning, it is important to recognize that content knowledge is not the only thing that affects student learning [1, 2, 3, 4]. These references argue that student beliefs about physics – about the structure of physics knowledge, the connection between physics and the real world, how to approach problem solving, and how to learn physics – play a substantial role in a student's ability to learn physics. Previous studies have used interviews to document and categorize students' beliefs in general [5] and about physics specifically [6]. In addition, several surveys have been developed to study these beliefs and to document the affects of various curricula on these beliefs. These surveys include the Views About Science Survey (VASS) [7], the Maryland Physics Expectation (MPEX) [8], the Epistemological Beliefs Assessment for Physical Science (EBAPS) [9], and the Colorado Learning Attitudes about Science Survey (CLASS) [10].

Studies using these surveys in introductory college physics courses found that the population of students in these introductory courses have a wide range of beliefs about physics and learning physics, with many students having quite novice views [8, 10]. For example, novices view physics as a series of disconnected facts and algorithms presented by the professor (the authority) that must be memorized and have no connection to the real world. While it is often not a stated or explicit goal, most physics instructors would like for the students to develop views about the nature of physics as a discipline that reflect the instructor's expert view [2]. Despite this 'hidden' goal, students' beliefs about physics and learning physics typically become more novice-like over of a standard introductory physics college course [8, 10, 11]. Understanding the broad importance of these beliefs and how to change these beliefs through different teaching practices is an active area of research. Prior research shows that some beliefs are correlated with a students' level of interest in physics [12,13]. In other work [11], we have found correlations between students' beliefs and learning gains on standard conceptual surveys (e.g. the Force Concept Inventory [14]), though further research is needed to understand the nature of any causal relationship.

Research has shown that students can hold seemingly contradictory ideas about physics and learning physics. Lising and Elby [6] introduce the idea that a student may believe one idea about studying physics for themselves (their personal epistemology), yet the same student may believe a different and contradictory idea holds true for physicists or people in general (their public epistemology). Students may think that they can't find coherence in their knowledge, but they would expect scientists to have coherence in their ideas. A similar phenomenon has been documented in student ideas about physics content. McCaskey [15, 16] asked students to complete the FCI twice. The first time students were asked to simply answer the questions. The second time students were asked to indicate both which answer they believed and how they thought a physicist would answer. This study found variations between what students believed and what answer they thought a physicist would believe.

Extending the work of Lising and Elby, our present study seeks to better understand students' beliefs about physics and learning physics by examining students' personal beliefs about physics and comparing those to what these same students think a physicist believes. It is valuable to know if novice students do not know what physicists believe about physics and learning physics, or if they know what physicists believe but do not hold these beliefs themselves. Knowing which of these scenarios is actually the case helps inform and guide the teaching approaches needed for developing more expert-like beliefs in students.

In this paper, we focus on the following questions:

1. Do students know what physicists believe about physics, the structure of physics knowledge, its connection to the real world, and how to approach problem solving and learning physics?
2. Do students' ideas about what physicists believe differ from their personal beliefs and are these ideas affected by college physics instruction?
3. Do students' ideas about what physicists believe differ across student populations, e.g. variations in type of physics course in which they are enrolled, gender, or previous high school physics experience?

We investigated these questions using the CLASS survey in a modified format where students were asked to respond to each statement with their personal opinion and their opinion of what a physicist would believe.

METHODOLOGY

We used a modified-format version of the CLASS survey [10] to measure students' beliefs in three introductory physics courses representing a diverse population of students. Introductory courses were selected in an attempt to reach students who were taking their first college physics course, allowing us to measure their beliefs before any college physics instruction and then again at the end of this first term of physics.

The original CLASS survey measures student beliefs about physics and learning physics. The survey consists of 42 statements (see Appendix A for complete list of statements) in which students are asked to rate their agreement or disagreement using a 5-point Likert scale. Each student's survey is scored by comparing the fraction of their responses that match the wellestablished expert response[1], resulting in an ‘Overall % Favorable’ score for each student. Individual statements are also evaluated by looking at the percentage of students who agree with the experts on that statement. For further details on scoring the CLASS see Appendix A and Ref. [10].

The modified CLASS survey used for this study contains the same 42 statements as the original and the same 5-point Likert scale. However, on the modified survey, students are asked to answer each statement twice, first with their personal belief and then again with how they think a physicist would respond, as shown in Figure 1. The survey instructions used in this study are provided in Appendix B. Student and course scores were calculated the same way as on the original CLASS survey, except each student or course had two scores - one “personal” score based on students’ personal opinion and one “physicist” score based on how the students thought a physicist would respond.

For this study, a particularly important aspect of the CLASS survey is its focus on eliciting students’ beliefs about physics in general, as opposed to their beliefs about a particular physics course. In the development of the CLASS, if a statement elicited a specific reference to the course as distinct from the discipline during validation interviews, it was rewritten. In the final set of interviews on the CLASS survey, student responses indicated that they were generally reflecting on their overall view of physics – explicit references to a specific course were infrequent. This design has important consequences for interpretation of the results of the survey. The “personal” responses to the CLASS survey are *not* directly a reflection of their views about the physics course in which they are enrolled, but instead are primarily a reflection of

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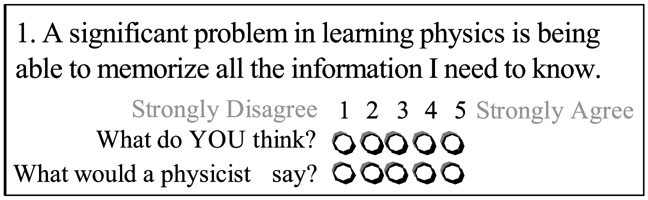
[1] Six of the statements on the survey do not have expert responses and are not scored. Expert responses (agree or disagree) for the other statements appear in Appendix A.

students overall personal beliefs, practices, and perspectives regarding physics and learning physics – shaped by some broader composite of their personal experiences and other pragmatic constraints (including physics courses).



1. A significant problem in learning physics is being able to memorize all the information I need to know.

Strongly Disagree 1 2 3 4 5 Strongly Agree

What do YOU think? ○ ○ ○ ○ ○

What would a physicist say? ○ ○ ○ ○ ○

FIG 1. An example statement from the modified version of the CLASS survey. Students are asked to express their personal opinion on each of the 42 statements ("personal" response) as well as their opinion of how a physicist would respond ("physicist" response).

The survey was given to students twice over the course of the semester. The pre-instruction survey was completed during the first week of classes, while the post-instruction survey was completed the week before the last week of classes. Collecting student survey responses both pre- and post- instruction allowed student beliefs to be studied before university physics instruction as well as to determine what effect, if any, the course had on their beliefs. Throughout the paper when comparisons are made between pre-and post-instruction data, a matched data set is used which considers only students who responded to both the pre and post surveys. When results are considered for pre-instruction only, the responses from all students who submitted the pre survey are used to improve the representation of all the students.

TABLE I. Demographic Information for Courses Surveyed

Courses Surveyed	**# of students**			**Dominant Population**	**Gender**[b]		**Previous Physics Experience**[b,c]			
	Enrolled	**Surveyed**[a] **Pre**	**Matched**		**Female**	**Male**	**None**	**HS Reg**[d]	**AP/IB**[e]	**College**
PHYS I-Calc	640	387	276	Engineers	29%	70%	13%	51%	30%	6%
PHYS I-Alg	528	414	342	Premed	65%	34%	31%	53%	10%	3%
Phys of Sound	212	118	84	Non-science	51%	46%	44%	39%	8%	9%

[a] The number of "matched" students surveyed includes only those who took both the pre and post survey. Gender and previous physics experience are based on percentage of students completing pre-survey.

[b] Since the demographic information is self reported and was not required, numbers may not total to 100%.

[c] Students are listed only under their most advanced physics course.

[d] Regular high school physics course

[e] Advanced Placement or International Baccalaureate physics class in high school.

Three different levels of introductory physics courses were surveyed during Fall 2005 covering a diverse population of students. Table I summarizes these populations. Physics I-Calc and Physics I-Alg are both first semester courses in a two-semester sequence of introductory physics, though each course serves a different population. Physics I-Calc is calculus-based, goes into more depth than Physics I-Alg, and is taken by mostly physics and engineering majors. Physics I-Alg is algebra-based and serves primarily biology and physiology majors with approximately 66% intending to attend some type of medical school. There is also a notable difference in the percentage of women in each course; the majority of students in Physics I-Alg are women while the majority are men in Physics I-Calc. For most of the students enrolled in these courses, Physics I-Calc or Physics I-Alg is required for their major/career choice. Physics of Sound is a semester-long course for non-science majors that covers waves and sound. It requires no previous physics experience though a small percentage (9%) of the students had taken a previous college-level physics course before enrolling. While Physics of Sound fulfilled a science requirement for most of the students enrolled, they chose it from many courses that satisfy this requirement. In all three courses, the students who took both pre and post surveys were comparable to the entire course based on course grade.

RESULTS AND DISCUSSION

In the following sections, we present and discuss the data collected in the three introductory physics courses. First, we compare students' "personal" and "physicist" scores, analyzing how these scores differ among the three courses and how they change with one semester of college instruction. We identify the individual survey statements for which most students are aware of the "expert" response and those for which they are not. In addition, we identify the statements for which students' responses most often show a discrepancy between their "personal" and "physicist" views. We also explore the relationship between these scores and students' gender and previous physics experience. Finally, we discuss some possible explanations for these discrepancies that are emerging from some preliminary research into this question.

A. Students "personal" vs. their "physicist" beliefs

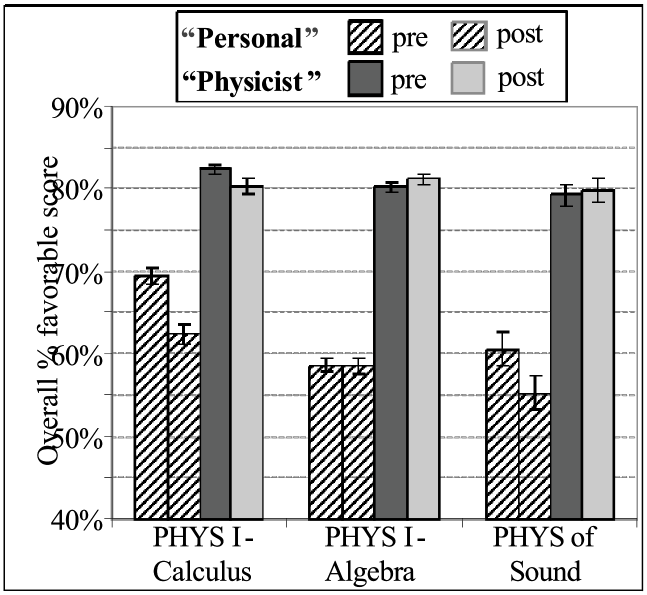


FIG 2. CLASS Overall % favorable scores by course. For each of the three courses surveyed, the average Overall % favorable "personal" scores - what the students believe about physics – is significantly lower than the "physicist" scores - what the students think a physicist believes about physics - for both pre and post instruction.

The comparison of students' "personal" and "physicist" beliefs in Figure 2 shows several notable features:

- Students' "physicist" scores are much more expert-like than their "personal" scores, indicating that while students know fairly well what physicists believe about physics and learning physics, they do not agree with these ideas, at least as they apply to their own personal contact with the discipline of physics and what practices they follow in learning physics and solving physics problems.
- Although these three courses represent quite different student populations, with corresponding differences in "personal" beliefs, their "physicist" responses are all

essentially the same, indicating that nearly all students start their college physics class with a good idea as to what physicists think about physics and learning physics. For comparison, the average Overall % favorable score for the 66 U.S. college physics faculty who have taken the CLASS survey is 91.4%, with a Overall % unfavorable score of 2.7%. See Appendix C for faculty scores on individual questions.

- Students' "physicists" scores are quite stable over the term, showing only small changes. The only statistically significant change in the "physicist" scores was in Physics I-Calc with the magnitude of the change being small (-2.2±0.9%, p=0.014)[2]. Thus, in these courses, students' ideas about physicists' beliefs are affected little if any by a semester of instruction. In contrast, their "personal" beliefs are usually more significantly, negatively affected as seen in Physics I-Calc (-6.9%±0.9%) and prior work [8, 11]. By explicitly attending to students beliefs in the classroom, some instructors have been able to avoid this general regression in beliefs as seen in Physics I-Alg or, in some cases, achieve shifts towards expert-like beliefs [4, 11].

There is a large difference between "personal" and "physicist" scores for each course suggesting that, in responding to the basic CLASS survey, students are not just giving the answer they think the instructor would give. Personal scores observed here are consistent with those obtained in these courses using CLASS in its standard single answer format [17].

In each course, the students' individual "personal" and "physicist" scores vary widely from novice to expert. Figure 3 shows an example of the distribution of "personal" and

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[2] The shift of -2.2±0.9% is calculated as the average of the individual pre-post shifts for all matched students. A student's individual pre-post shift is calculated as his post minus pre "physicist" Overall % Favorable score. The difference of the pre and post averages (as opposed to the average of the differences) gives -2.1±1.1%.

"physicist" scores on the pre-instruction survey for Physics I-Alg. While the "personal" scores show a wide distribution, the "physicist" scores are grouped towards very expert-like with 60% of the students scoring better than 80% on Overall % Favorable.

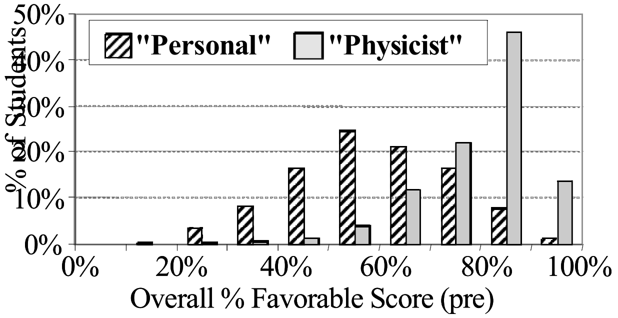

FIG 3. "Personal" and "Physicist" score distributions for Physics I-Alg pre-instruction.

TABLE II. Statements with the most novice-like "Physicist" scores

Statement (expert response)	Faculty[b] (% fav)	Statement score[a] (% favorable) pre "physicist" Phys I-Calc	Phys I-Alg	Phys of Sound	post "physicist" Phys I-Calc	Phys I-Alg	Phys of Sound
8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values. (disagree)	83%	27%	27%	21%	31%	41%	29%
12. I cannot learn physics if the teacher does not explain things well in class. (disagree)	63%[c]	27%	22%	33%	32%	28%	28%
18. There could be two different correct values for the answer to a physics problem if I use two different approaches. (disagree)	79%	63%	50%	41%	68%	59%	50%
27. It is important for the government to approve new scientific ideas before they can be widely accepted. (disagree)	100%	56%	49%	55%	58%	47%	57%
22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations. (disagree)	91%	59%	50%	52%	60%	49%	49%

[a] Percentage of students in each class who agreed with the expert response for that statement.
[b] Percentage of the 66 U.S. university and college faculty who agreed with the expert response for this statement. See Appendix B for the faculty responses for other statements.
[c] This statement has the lowest consistency among experts of the scored statements – 63% disagree and 28% choose neutral. The average % of neutral responses for the scored statements is 6%.

While students are quite expert-like in their "physicist" responses for most of the statements, there are a few statements for which many students did not know the expert response. In Table II, we list the five statements with an average "physicist" score of less than 55% favorable on the pre-instruction survey. Statements 8 and 12 were especially novice-like with less than 35% of students correctly identifying the expert response in any of the classes. While there is no definitive link between the five statements, several of them appear to depend on greater knowledge about the discipline than other survey statements. The scores remained fairly constant from pre-instruction to post-instruction.

% of Students Who "Split"			
PHYS I-Calc	PHYS I-Alg	Phys of Sound	Statements (expert response)
48%	67%	60%	3. I think about the physics I experience in everyday life. (agree)
41%	67%	64%	25. I enjoy solving physics problems. (agree)
49%	56%	52%	36. There are times I solve a physics problem more than one way to help my understanding. (agree)

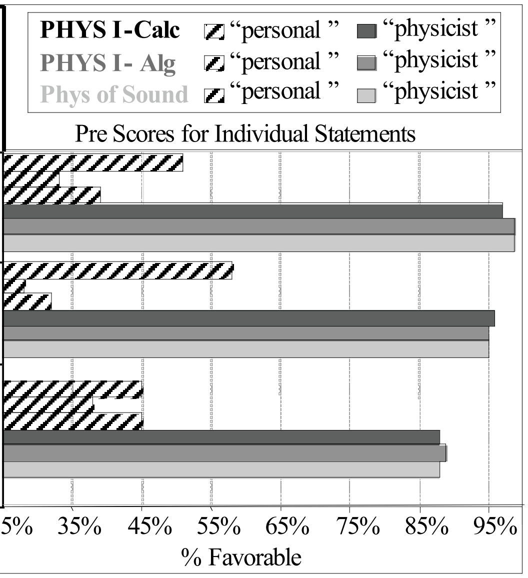

FIG. 4. Statements with the most "splits"- that is where a student's "personal" and "physicist" response do not match. Only pre-instruction data is shown. More than 50% of the students surveyed "split" on these three statements. The "Personal" (striped bars) and "Physicist" (solid bars) % favorable scores for these statements show large differences.

Analyzing individual statements gives a clearer picture of how students view physics and learning physics. Here we examine for which statements students do, and do not, "split". A student's response is considered a "split" when their "personal" response for a statement is different from their "physicist" responses for the same statement (e.g. "personal" = strongly agree, “physicist” = neutral). As with previous scoring methods, for the purposes of defining a “split” strongly agree and agree are considered equivalent responses as are strongly disagree and disagree.

Figure 4 shows the statements with the most “splits”- defined as more than 50% of the students “split” on these statements on the pre-instruction survey. Students generally have fairly novice-like “personal” beliefs for the statements with the most “splits”, although the three statements shown in Figure 4 are not the statements with the most extreme novice-like “personal” beliefs. The statements with the most “splits” have a common subject - namely how people personally relate to physics – and provide some insight into probable reasons for the measured differences between students’ “personal” and “physicist” beliefs.

% of Students Who “Split”			
PHYS I-Calc	PHYS I-Alg	Phys of Sound	Statement (expert response)
5%	7%	8%	29. To learn physics, I only need to memorize solutions to sample problems (disagree)
8%	11%	12%	23. In doing a physics problem if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem. (disagree)
8%	14%	13%	26. In physics, mathematical formulas express meaningful relationships among measurable quantities. (agree)
11%	15%	13%	10. There is usually only one correct approach to solving a physics problem. (disagree)

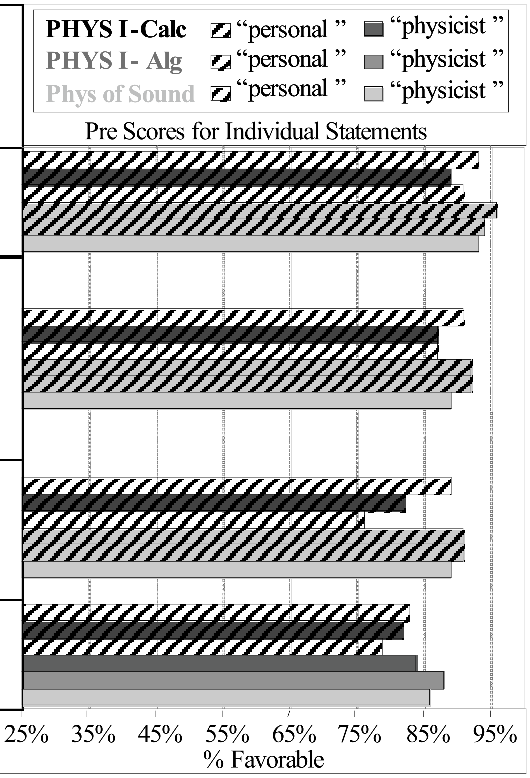

FIG. 5. Statements with the fewest “splits” in the pre-instruction responses. Less than 15% of the students surveyed “split” on these statements. “Personal” (striped bars) and “Physicist” (solid bars) % favorable scores for these statements show differences of 5% on average.

Figure 5 shows the statements for which the fewest students "split" on the pre-instruction survey. On average 29% of the students "split" on a given statement, while less than 15% of the students surveyed "split" on the statements shown in Figure 5. The post-instruction results are very similar. We note that these statements with the fewest "splits" are those statements where the students "personal" beliefs are most expert-like. Thus, the consistency between the "personal" and "physicist" responses is resulting from students agreeing with the expert, rather than from students misjudging expert responses.

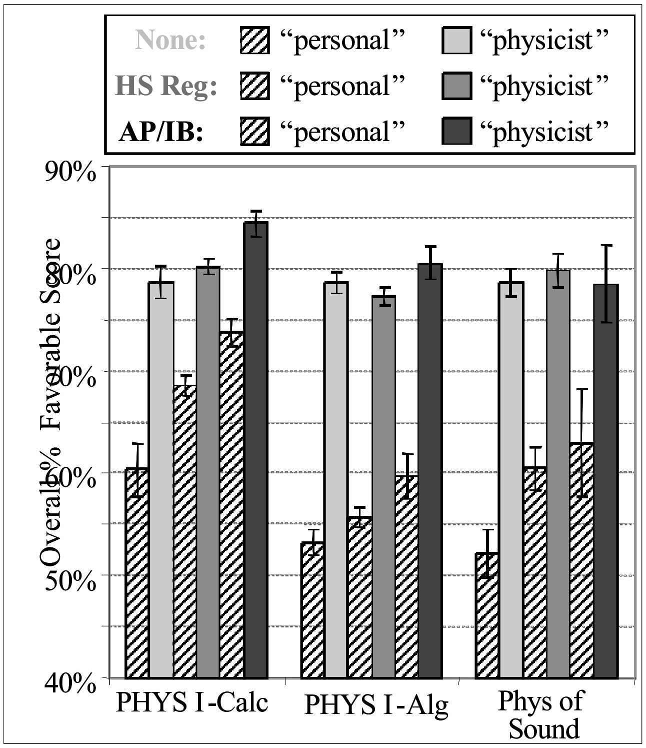

FIG. 6. Pre-Instruction CLASS scores by previous and current physics courses. Error bars represent plus and minus one standard error of the mean.

B. The influence of prior physics courses

To start addressing the question of what factors are related to students' beliefs about physics, we looked at their high school physics experience. The 5% of the students who have completed at least a semester of college physics were not included in this analysis. The following analysis looks at the most advanced course the students had completed in high school – no previous physics course, a regular high school physics course, or an AP (advanced placement) or IB (international baccalaureate) physics course.

Figure 6 shows the average scores for each of the three surveyed courses broken down by the students' previous physics experience. What is most striking is how little correlation there is between the students' "physicist" responses and their high school physics experience, compared to that evident in the "personal" beliefs. Except for the AP/IB group in Physics I-Calc, which has slightly more expert "physicist" responses, all other "physicist" responses are essentially identical. The "personal" beliefs show a much larger variation, with "personal" score correlating with both the choice of college course and high school physics course. Students choosing to take more advanced physics courses have more expert-like "personal" scores. It seems plausible based on our data on the impact of college physics courses that most, if not all, of these correlations are due to a selection effect. In this case, students are selecting their college and high school courses according to their personal beliefs, rather than their high school physics courses changing their beliefs to be more expert-like. However further research is needed to establish a causal relationship. It is clear that students have a rather accurate understanding of physicists' beliefs even with widely different high school course experiences.

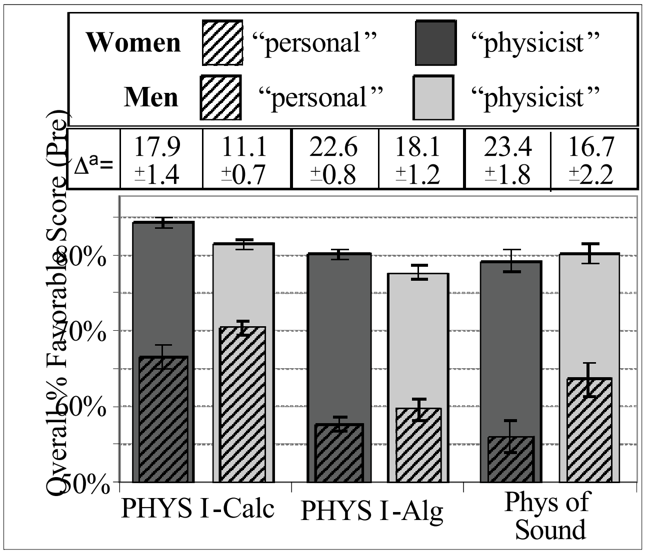

FIG. 7. "Personal" (striped bars) and "Physicist" (solid bars) pre scores by gender and current course. Error bars indicate the standard error on the mean. Note the change in scale.
[a] Average of the difference (Δ) between "personal" and "physicists" pre scores for *each* student in that group and +/- one standard error on the average.

C. Women have larger splits

Previous studies have shown that gender plays a role in students' ideas about physics and learning physics [10]; it is therefore important to study if gender relates to students' ideas about what physicists' believe. Figure 7 shows the gap (Δ) between "physicist" and "personal" pre-instruction scores (calculated as "physicist" score – "personal" score) for each gender. Since the previous section has shown the importance of the current course on student beliefs, this section will continue to separate students by their course. Research on the original CLASS survey shows that men generally have more expert-like personal beliefs than women [10], and that trend is also evident here, though the difference in the overall score is more modest than in particular categories of beliefs. The physicist data shows that women have a slightly better perception of what physicists' believe, with the difference being statistically significant for Physics I-Calc (p=0.004) and marginally different for Physics I-Alg (p=0.04)[3]. As a result, women have a larger gap (Δ) between their "physicist" scores and their "personal" scores than their male classmates; comparison of the gap data for the 3 courses shows the gaps for men and women are statistically significantly different for Physics I-Calc ($p<0.001$) and for Physics I-Alg (p=0.002), while being marginally different for Physics of Sound (p=0.022)[3,4]. This difference suggests that although women know what physicists believe somewhat better than men, they see those beliefs as having less validity for themselves.

Figure 8 shows the pre-responses of the Physics I-Alg men and women on the 36 individual statements that are scored, ordered by the women's "physicist" scores. From this data, we examine the individual statement gaps for both women and men to determine the source of the larger overall gap observed for women in Figure 7. The women's gap for a particular statement would, for example, be calculated as the percentage of women who agreed with the expert when responding for their "physicist" view minus the percentage of women who agreed with the expert when responding for their "personal" view. Figure 9 shows how the gap between women's "physicist" and "personal" scores compares to the men's gap by statement. Based on these data, the gender difference in the overall gaps represented in Figure 7 is not due to large differences on a few questions, but rather due to small to modest differences on many questions.

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[3] Statistical significance was tested using three independent t-tests. Applying a Bonferroni correction for multiple comparisons, a p-value of less than 0.017 is considered significant to protect against Type I error at the 0.05 level.

[4] The gender differences in the gap between "personal" and "physicist" scores (Δ) has greater statistical significance (lower p-values) than can be seen in the difference of the average "personal" and "physicist" scores because the gap is calculated for *each* student as the difference in each students' % favorable "personal" and "physicist" scores. The variability in this gap is less than would be predicted based solely on the variability in the "personal" and "physicist" scores.

Women have a larger gap between their “physicist” and “personal” scores (a value greater than zero in Figure 9) on 78% of the scored statements. Six of the seven statements that had gap differences greater than +10% had men’s “personal” scores that were notably more expert-like than the women’s, while the physicist scores were comparable across gender. These six statements (statements 3, 5, 14, 25, 34, and 40) all dealt with either the student’s interest in physics or the student’s confidence in his or her problem solving abilities. Thus, for the statements with the largest differences in the gaps, the gaps are due to differences in men and women’s “personal” responses, not their “physicist” responses. For many of the other statements, where the differences are smaller, the differences in the gaps are due to gender differences in both the “physicist” and “personal” views as reflected in Figure 7.

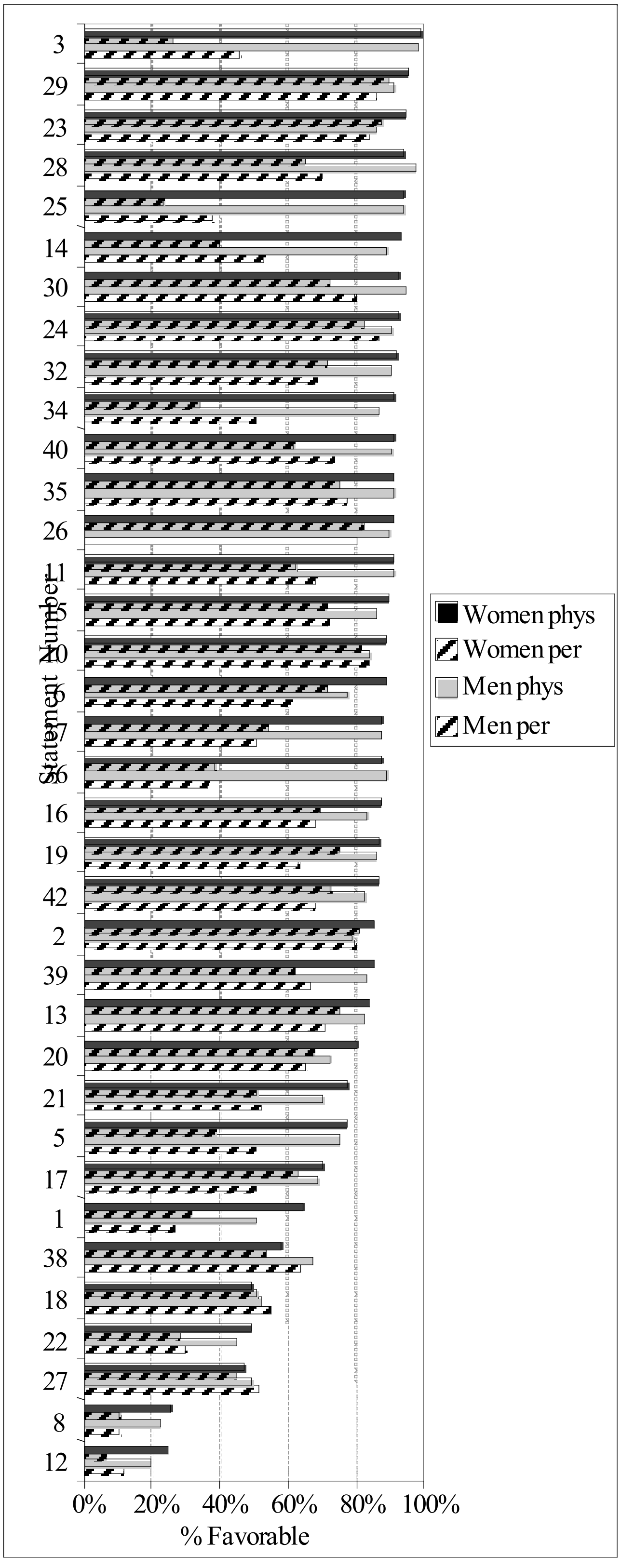

FIG. 8. Individual "personal" and "physicist" statement scores (pre) by gender for the Physics I-Alg course, sorted by women's "physicist" score.

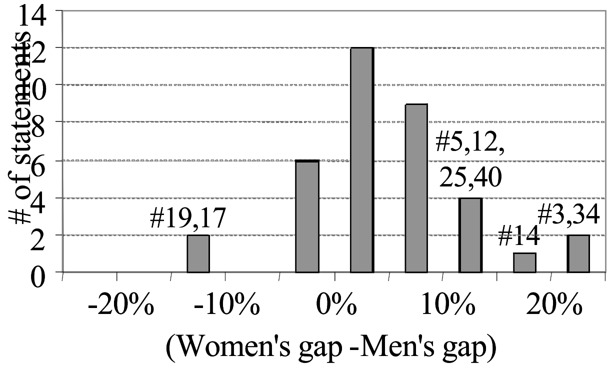

FIG. 9. Difference between women's and men's gap for individual statements for the Physics I-Alg course. For many statements, the gap between women's "physicist" and "personal" pre scores is slightly larger than the gap between men's "physicist" and "personal" pre scores.

D. Possible Reasons for the Splits

While establishing the *reasons* that students see physicist beliefs as not applying to themselves is beyond the scope of this work, there are some plausible explanations that have emerged from interviews conducted during the validity testing of the CLASS survey and from a few preliminary interviews connected with this study. It appears that the most prominent reasons for students splitting on their responses are: 1) believing that physicists would inherently be more interested in physics and aware of physics phenomena, otherwise they would not have gone into the profession, 2) seeing that the greater experience and expertise of physicists would influence their abilities and beliefs, and 3) believing that the kinds of physics problems that students see are less authentic and therefore are perceived differently and approached differently than the sorts of problems a physicist faces, which are seen as being more in depth, involving harder problems, not requiring memorization, and putting more at stake than the student's homework problems. Other reasons expressed in these preliminary interviews include statements reflecting what students see as most sensible for their personal situation: students saying they are lazy (their words) in their approaches to problem solving compared to physicists; students saying that while they want to or should take the more expert-like approach, in reality they don't because they don't have the time or need; and students believing physicists, or other people in general, may have a different approach to learning than themselves but not wanting to assume what approach that would be. Additional research is needed to definitively establish the reasons for the differences between students' personal and physicist responses and to further explore the gender differences observed in the current study.

CONCLUSION

In our comparison of students' "personal" and "physicist" scores on the CLASS survey, we find that most students with novice beliefs about physics and learning physics are, in fact, quite aware of what physicists believe about physics and learning physics; they just don't believe these ideas are valid, relevant, or useful for themselves. Women showed a larger gap between their "physicist" scores and their "personal" scores compared to the men in the same course. This gap suggests that while women are better at identifying what ideas "physicists" believe, they are less inclined to feel these ideas are valid or relevant for their experiences.

Remarkably, students' "physicist" beliefs are quite consistent across populations and different high school physics experiences. In contrast, "personal" beliefs differ by choice of college physics course and previous high school physics experience. Course instruction is seen to affect students' "personal" beliefs, but it has relatively little impact on students' "physicist" beliefs.

These data indicate that students' formal and informal educational experiences are failing to provide experiences in which expert-like beliefs are useful, relevant, or necessary. The implication and challenge for instruction is that, in order to achieve more expert-like beliefs in students, the instructor should concentrate on finding ways – through teaching practices or curriculum design – that go well beyond telling students about how experts view physics, but instead focus on making adoption of expert-like views truly useful and relevant for students.

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APPENDIX A: CLASS

<u>CLASS Scoring:</u> Thirty-six of the 42 statements are included in the "Overall" score. Of the other six statements, two have been slated for revision (statements 7, 41), three statements are learning style questions (statements 4, 9, 33) and therefore do not have a consistent expert response, and one statement is used to find students who are not taking the survey seriously (statement 31). Each of the 36 scored statements have an expert response which was developed from interviews and surveys with physics professors (see statement list below). Each student receives an "Overall % favorable" score based on the percentage of statements for which their response agreed with the expert response (strongly agree and agree are combined for the purpose of scoring as are strongly disagree and disagree). A "% unfavorable" score is also calculated for each student as the percentage of statements for which the student disagreed with the expert response. Since a student can choose to be neutral on some statements, the percentage favorable and the percentage unfavorable do not necessarily add to 100 percent. Course, or other group, scores are calculated by averaging over the scores of the students in that group.

CLASS Statements and (expert responses):

1. A significant problem in learning physics is being able to memorize all the information I need to know. (disagree)

2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer. (agree)

3. I think about the physics I experience in everyday life. (agree)

*4. It is useful for me to do lots and lots of problems when learning physics.

5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic. (disagree)

6. Knowledge in physics consists of many disconnected topics. (disagree)

*7. As physicists learn more, most physics ideas we use today are likely to be proven wrong.

8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values. (disagree)

*9. I find that reading the text in detail is a good way for me to learn physics.

10. There is usually only one correct approach to solving a physics problem. (disagree)

11. I am not satisfied until I understand why something works the way it does. (agree)

12. I cannot learn physics if the teacher does not explain things well in class. (disagree)

13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations. (disagree)

14. I study physics to learn knowledge that will be useful in my life outside of school. (agree)

15. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works. (agree)

16. Nearly everyone is capable of understanding physics if they work at it. (agree)

17. Understanding physics basically means being able to recall something you've read or been shown. (disagree)

18. There could be two different correct values for the answer to a physics problem if I use two different approaches. (disagree)

19. To understand physics I discuss it with friends and other students. (agree)

20. I do not spend more than five minutes stuck on a physics problem before giving up or seeking help from someone else. (disagree)

21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it. (disagree)

22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations. (disagree)

23. In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem. (disagree)

24. In physics, it is important for me to make sense out of formulas before I can use them correctly. (agree)

25. I enjoy solving physics problems. (agree)

26. In physics, mathematical formulas express meaningful relationships among measurable quantities. (agree)

27. It is important for the government to approve new scientific ideas before they can be widely accepted. (disagree)

28. Learning physics changes my ideas about how the world works. (agree)

29. To learn physics, I only need to memorize solutions to sample problems. (disagree)

30. Reasoning skills used to understand physics can be helpful to me in my everyday life. (agree)

*31. We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question to preserve your answers.

32. Spending a lot of time understanding where formulas come from is a waste of time. (disagree)

*33. I find carefully analyzing only a few problems in detail is a good way for me to learn physics.

34. I can usually figure out a way to solve physics problems. (agree)

35. The subject of physics has little relation to what I experience in the real world. (disagree)

36. There are times I solve a physics problem more than one way to help my understanding. (agree)

37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed. (agree)

38. It is possible to explain physics ideas without mathematical formulas. (agree)

39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem. (agree)

40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own. (disagree)

*41. It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.

42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented. (agree)

* These statements are not scored.

APPENDIX B: INTRODUCTORY INSTRUCTIONS TO CLASS SURVEY

The introductory instructions to the CLASS survey used in this study were as follows:

> Here are a number of statements that may or may not describe your beliefs about learning physics. You are first asked to rate each statement according to your beliefs by selecting a number between 1 and 5 where the numbers mean the following:
>
> 1. Strongly Disagree
> 2. Disagree
> 3. Neutral
> 4. Agree
> 5. Strongly Agree

Choose one of the above five choices that **best expresses your feeling** about the statement. Then, please select the choice that **you think a physicist would give**. If you don't understand a statement, leave it blank. If you have no strong opinion or think an physicist would have no strong opinion, choose 3.

We are asking that you express your own beliefs. **Your answers will not affect your grade.** Your instructor will never see your individual answers, only whether you participated and the class results as a whole. This information will be very helpful to us in an effort to design more effective physics courses.

APPENDIX C: FACULTY RESPONSES

The following table shows the responses from 66 U.S. university and college physics faculty on the CLASS. The responses are given as a percentage of the faculty who agreed or disagreed with each statement. The accepted expert response is bolded and underlined. Statements which are not scored are not included in the table.

Expert responses to statements					
#	Agree	Disagree	#	Agree	Disagree
1	2%	**83%**	22	5%	**91%**
2	**97%**	0%	23	2%	**98%**
3	**94%**	2%	24	**92%**	3%
5	8%	**80%**	25	**92%**	0%
6	2%	**95%**	26	**98%**	0%
8	6%	**83%**	27	0%	**100%**
10	3%	**92%**	28	**95%**	0%
11	**92%**	2%	29	0%	**100%**
12	9%	**63%**	30	**100%**	0%
13	6%	**86%**	32	2%	**97%**
14	**83%**	3%	34	**92%**	2%
15	**92%**	2%	35	0%	**100%**
16	**80%**	5%	36	**89%**	3%
17	0%	**94%**	37	**91%**	3%
18	10%	**79%**	38	**82%**	14%
19	**88%**	5%	39	**97%**	3%
20	0%	**100%**	40	2%	**95%**
21	0%	**95%**	42	**98%**	0%

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