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Chemistry vs. Physics: A Comparison of How Biology Majors View Each Discipline

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Abstract. A student's beliefs about science and learning science may be more or less sophisticated depending on the specific science discipline. In this study, we used the physics and chemistry versions of the Colorado Learning Attitudes about Science Survey (CLASS) to measure student beliefs in the large, introductory physics and chemistry courses, respectively. We compare how biology majors – generally required to take both of the courses – view these two disciplines. We find that these students' beliefs are more sophisticated about physics (more like the experts in that discipline) than they are about chemistry. At the start of the term, the average % Overall Favorable score on the CLASS is 59% in physics and 53% in chemistry. The students' responses are statistically more expert-like in physics than in chemistry on 10 statements ($P \leq 0.01$), indicating that these students think chemistry is more about memorizing disconnected pieces of information and sample problems, and has less to do with the real world. In addition, these students' view of chemistry degraded over the course of the term. Their favorable scores shifted -5.7% and -13.5% in 'Overall' and the 'Real World Connection' category, respectively; in the physics course, which used a variety of research-based teaching practices, these scores shifted 0.0% and +0.3%, respectively. The chemistry shifts are comparable to those previously observed in traditional introductory physics courses.

Keywords: Beliefs, Interest, Learning, CLASS, Undergraduate education, Chemistry, Physics.
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INTRODUCTION

Over the last decade, students' beliefs about physics and learning physics has become an active area of research within the physics education research community. It is well established that, in introductory college physics, the majority of students start the term with relatively novice-like beliefs about physics – seeing it as isolated pieces of information that have little connection to the real world but must be memorized.[1,2,3] These studies show that students' enrolled in algebra-based physics courses have more novice-like beliefs than those enrolled in calculus-based physics. In both courses, students' beliefs typically degrade – that is become more novice-like – over the course of most introductory physics classes.[1,2,3] In addition, our prior work found correlations between students' beliefs and other important educational outcomes, such as content learning gain, choice of major, and level of interest in physics.[1,4]

These findings have led to efforts to identify teaching practices that explicitly target and support the development of expert-like beliefs within these introductory courses. Some courses with modest efforts to implement these practices have succeeded in avoiding the typical regression, while others with more extensive interventions have shown improvements. [1,5]

In this paper, we compare students' beliefs about physics and chemistry – two disciplines where experts' beliefs about their respective disciplines are quite similar. While we are aware of some efforts in the chemistry education community to investigate beliefs [6], we are not aware of any direct comparisons between physics and chemistry. We ask several questions: Do introductory students have more expert-like beliefs about chemistry or physics? In which categories of beliefs are students' views different between the two disciplines? Do chemistry and physics courses have similar impacts upon students' beliefs about the disciplines? Do students' beliefs in chemistry and physics show similar correlations with other educational outcomes?

STUDY DESIGN

Over the past year, we used the physics and chemistry versions of the Colorado Learning Attitudes about Science Survey (CLASS-Physics and CLASS-Chemistry) [3] to measure student beliefs both at the start (pre) and end (post) of introductory courses within these disciplines. The CLASS-Physics and

CLASS-Chemistry surveys consist of 42 and 50 statements, respectively, to which students respond using a 5-point Likert scale. Thirty-four of these statements meet the criteria for the comparative 'Overall' score – the statements are common between the two surveys (with the word "physics" replaced with the word "chemistry") and have a consistent expert response. These 34 statements are used to determine each student's 'Overall' % favorable belief score – the percentage of statements for which his/her response agrees with that of an expert. Eight belief categories (e.g. 'Real World Connection') are scored using groupings of 4 to 8 statements. The details of the design, categorization, and validation of the CLASS-Physics are reported by Adams et al. [3]. All of the CLASS-Chemistry statements have been validated with student interviews and faculty responses. A paper describing this work is in preparation. [7]

In addition to these statements, we included two supplementary questions on the survey to monitor students' level of interest in physics (chemistry):

Currently, what is your level of interest in [discipline]? (very low, low, moderate, high, very high)
During the semester, my interest in [discipline]…
(increased, decreased, stayed the same)

We purposely chose to use vague questions as opposed to questions that are more specific measures of interest, such as whether students would like to learn more physics. This approach was taken in an effort to measure students' composite affective response towards physics or chemistry. The student's answer naturally depends upon the range of factors relevant to how she personally identifies what makes something interesting.

We have collected CLASS-Physics responses in a first-term, algebra-based Physics I course (Phys I) and CLASS-Chemistry responses in a first-term, introductory general chemistry course (Chem I). In prior research, we have found differences in students beliefs correlating with choice of major [1,3]; thus, in this study, we focus on just the biology majors[1]. We choose first-term courses because college physics courses have been shown to alter student beliefs. [1,2,3] With these data, we are able to compare two large and similar populations of students because there are a large number of biology majors and the students are required to take both courses to fulfill their majors.

From Table 1, we see that both courses were large lecture courses (over 500 enrolled) with a large number of biology majors, the majority of which are women. The results presented here are for the 156

TABLE 1. Introductory courses surveyed

		Chem I	Phys I – Alg
Total # of students		812	553
Total # of bio students		362	330
Bio with pre/post surveys	Total #	156	212
	% women	70.3%	72.2%
	% men	28.4%	27.4%

(Chem I) and 212 (Phys I) biology-majors for which we collected matched pre- and post- surveys. The instructor for the Phys I course is very familiar with research findings in PER and incorporated many research-based practices into the course, including: in-class concept questions where student-student discussions are highly encouraged and reasoning/sense-making is emphasized; interactive feedback in lecture where students use H-ITT [8] "clickers" to vote; conceptual questions on homeworks and exams; and labs revised to incorporate more discovery. In implementing these practices, the instructor explicitly worked to promote expert beliefs. Although the Chem I course used concept tests and clickers, the course was comparatively traditional, with less emphasis on peer discussion, reasoning, and conceptual learning.

RESULTS AND DISCUSSION

Incoming students' beliefs. Students' responses on the pre-course surveys were compared to identify difference between biology majors' view of physics and chemistry prior to any college instruction in the discipline. Statistically significant differences (p<0.01) between their responses to the CLASS-Physics and CLASS-Chemistry surveys were measured for the 'Overall' score and for three categories – 'Real World Connection', 'Conceptual Connections' and 'Applied Conceptual Understanding'. In Figure 1, we see that biology majors have consistently more expert-like beliefs about physics and learning physics than about

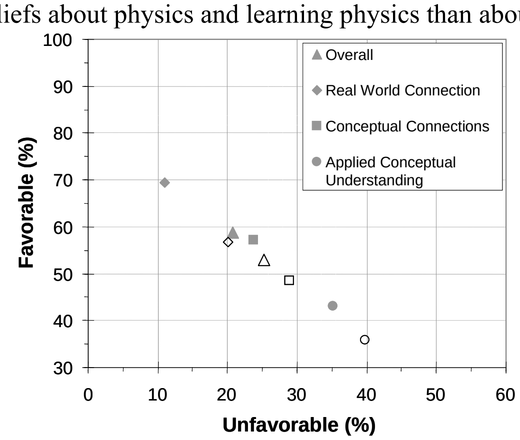
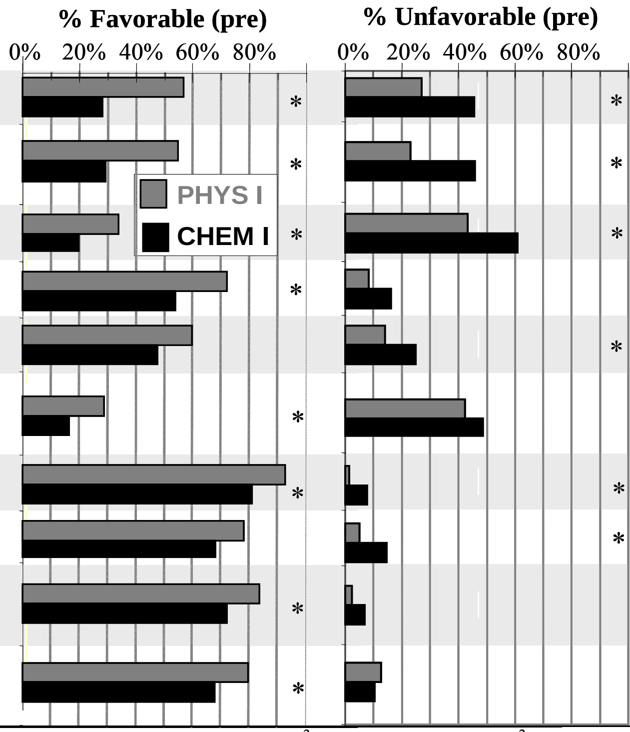


FIGURE 1. CLASS survey scores for biology majors at the start (pre) of Phys I (solid) and Chem I (hollow). The students were consistently more expert-like in their view of physics, with the difference being statistically significant (p<0.01) for both 'Overall' and the 3 categories shown.

[1] including students majoring in Molecular, Cellular, and Developmental Biology, Ecology and Evolutionary Biology, and Integrative Physiology as well as the now-discontinued majors of Kinesiology and Environmental, Population, and Organismic Biology

TABLE 2. Comparison of *pre* responses on individual CLASS-Physics and CLASS-Chemistry statements

Statements ([ ] = chemistry or physics)	**Diff[1]**
38. It is possible to explain [ ] ideas without mathematical formulas. (Agree)	-0.34
37. To understand [ ], I sometimes think about my personal experiences and relate them to the topic being analyzed. (Agree)	-0.33
1. A significant problem in learning [ ] is being able to memorize all the information I need to know. (DA)	-0.22
6. Knowledge in [ ] consists of many disconnected topics. (Disagree)	-0.20
17. Understanding [ ] basically means being able to recall something you've read or been shown. (DA)	-0.15
22. If I want to apply a method used for solving one [ ] problem to another problem, the problems must involve very similar situations. (Disagree)	-0.14
29. To learn [ ], I only need to memorize solutions to sample problems. (Disagree)	-0.13
35. The subject of [ ] has little relation to what I experience in the real world. (Disagree)	-0.13
26. In [ ], mathematical formulas express meaningful relationships among measurable quantities. (Agree)	-0.12
13. I do not expect [ ] equations to help my understanding of the ideas; they are just for doing calculations. (Disagree)	-0.10



1. Diff is measured by calculating the "linear distance from expertness", or SQRT((1-fraction favorable)^2 + (fraction unfavorable)^2) for the Phys I and Chem I responses and taking the difference of these two values (Phys-Chem). *These responses are statistically different PHYS I vs. CHEM I using two-tailed z-tests p<0.01.

chemistry across these categories. The most dramatic difference is observed in the 'Real World Connection' category where the % favorable scores are 69.3% for physics and only 56.8% for chemistry, indicating that these biology majors see physics as substantially more connected to the real world – as both describing and being useful to understand real world experiences.

Comparing students' responses to individual statements provides more insight into how their beliefs about physics and chemistry differ. We used "distance from expertness" (as described in the table) to compare the two groups and to quantify the difference. This measure allows one to account for both the % favorable and % unfavorable responses. In Table 2, we list the 10 statements for which the biology majors had statistically different ($p<0.01$) responses for physics and chemistry. In all cases, the students responded more expert-like in physics than in chemistry. Several themes are apparent. In comparison to physics, biology majors see chemistry as being *more* about memorizing disconnected pieces of information and sample problems, as having *less* to do with the real world, and as being *less* conceptual, needing math to explain chemistry but not making sense of the math. There are some differences between the responses for men and women in chemistry and physics, but there appears to be no strong discipline-specific aspect to these differences.

We find it especially interesting that the biggest difference is on the statement, "It is possible to explain physics (chemistry) ideas without mathematical formulas." With physics being more mathematically intensive than chemistry, we would have predicted that students would have thought physics was more about math than was chemistry.

The cause of these differences in beliefs is not revealed by these data. We speculate that this discrepancy develops from their prior experiences with science in high school and earlier. One might suspect that these differences could be due to the maturity or experience of the students (biology majors are generally freshmen in chemistry and sophomores in physics); however, as discussed in the next section, the shifts in beliefs observed in chemistry do not support this logic.

Shifts in beliefs. Figure 2 shows the shifts in CLASS scores over the course of the term (pre-to-post) for the biology majors in the Phys I and Chem I courses. Only categories for which the shifts are statistically different ($p<0.01$) are included. In Chem I, we see the biology majors shifting to be much more novice-like in their beliefs about chemistry – a result consistent with the typical shifts observed in introductory physics courses.[1,2,3] In the Phys I course, however, we observe students beliefs holding steady in most cases. We attribute this to the Phys I instructor's emphasis on

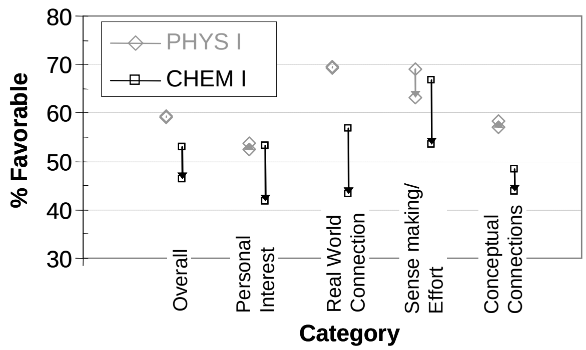


FIGURE 2. Pre-post shift for CLASS-Chemistry and CLASS-Physics scores where there is a statistically significant difference in the shifts (p<0.01).

conceptual understanding and reasoning, his infusion of real world examples, and his use of concept tests and peer discussion in class.

Beliefs and Self-rated Interest. In prior work [4], we found a strong correlation between students' beliefs as measured by the CLASS and their self-rated interest as measured by the supplemental questions described above. In Figure 3, we see the strong correlation exists for chemistry as well as physics. In Phys I, where students' beliefs did not regress, 52% of students also stated that their interest increased over the term with only 16% stating that their interest decreased. In Chem I, however, only 32% of students' stated their interest increased, while 31% stated their interest decreased.

In our prior work, we showed that students whose interest increases most often cite the connection between physics and the real world as the reason for their increased interest.[4] Thus, the decline observed in the 'Real World Connection' category for Chem I seems particularly important, and would suggest that efforts to better connect chemistry to the real world may lead to more interest in chemistry among this population of biology majors.

CONCLUSION

We observe significant differences in biology majors' beliefs about physics and their beliefs about chemistry. In all measures, these students have more novice-like beliefs about chemistry, specifically seeing chemistry as *more* about memorizing and *less* about the real world. Since these differences are present at the *start* of these first-term introductory courses, these differences in beliefs were established by some combination of prior experiences. It would be interesting to investigate whether these differences may stem from differences in the way in which physics and chemistry are taught in middle and high school.

As with physics, we see a correlation between students' measured beliefs and their self-rated interest; while these data do not illuminate the cause for this

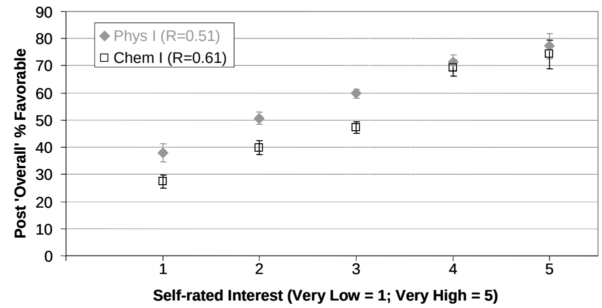


FIGURE 3. Post CLASS 'Overall' % favorable scores versus students' self-rated interest for Phys I (solid) and Chem I (hollow). Error bars show standard error of the mean.

correlation, certainly a plausible explanation is that with more expert-like beliefs, students see physics or chemistry as connected, powerful ideas that are useful for solving a wide variety of relevant problems, and thus more interesting. Establishing the nature of this correlation is planned for future work.

As with many physics courses, we see that introductory chemistry courses, even those that use concept tests and clickers, may lead to significant declines in students beliefs about chemistry and learning chemistry. Physics courses where reforms have succeeded in avoiding this typical decline, may serve as a useful model for reforming chemistry courses. We will test this idea as the Chem I course will be undergoing significant reform efforts over the next few terms, with part of their objective being to reduce this observed decline in students' beliefs.

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