

Attitudinal gains across multiple universities using the Physics and Everyday Thinking curriculum

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Abstract. Instructional techniques based on research in cognitive science and physics education have been used in physics courses to enhance student learning. While dramatic increases in conceptual understanding have been observed, students enrolled in these courses tend to move away from scientist-like views of the discipline and toward novice-like views, as measured by various assessment instruments. It has been proposed that course materials and instruction which explicitly addresses epistemology, the nature of science, and the nature of learning will help students develop views more closely aligned with the views of scientists. The Physics and Everyday Thinking (PET) curriculum has specific goals for helping non-science majors explicitly reflect on the nature of science and the nature of learning science. We show that in PET courses with small and large enrollments, shifts toward expert responses ranged from +4% to +16.5% on the Colorado Learning Attitudes about Science Survey. These results are compared to results from other studies using a variety of similar assessment instruments.

Keywords: physics education, curriculum, student beliefs, teacher preparation

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INTRODUCTION

The work in this paper addresses the national need for increased scientific literacy among the general public as well as increased science literacy among future and practicing elementary and middle school teachers [1][2]. Among the issues raised in national reports that focus on these issues is the need for undergraduate science courses that not only address fundamental content goals but also explicitly address the nature of scientific knowledge, science as a human endeavor, and the unifying concepts and processes of science. Researchers and curriculum developers have responded to this call by developing inquiry-based, physical science curricula especially for the post-secondary, non-science major population. Such curricula include *Physics By Inquiry* [3], *Powerful Ideas in Physical Science* [4], *Workshop Physical Science* [5], *Operation Primary Physical Science* [6], *Physics and Everyday Thinking* [7], and *Physical Science and Everyday Thinking* [8]. In most cases, large conceptual learning gains have been found to be associated with these specialized curricula [6][9][10]. However, little work has been done to determine how such courses might impact students' views about science, their views about learning science, and their understandings of various aspects of the nature of science.

Research has consistently demonstrated that K-12 teachers and their students do not develop desired understandings of the nature of science [11]. The nature of science is a phrase used to distinguish scientific knowledge from other ways of knowing through “the use of empirical standards, logical arguments, and skepticism” [1]. Abd-El-Khalick showed that while pre-service elementary teachers have difficulty learning about the nature of science, they develop a better understanding of certain aspects of the nature of science when nature of science instruction was embedded within instruction on specific scientific content [11]. Yet, few science teacher education courses focus on *content* and few science content courses focus on the *nature*

of science and the *nature of learning science*. Not only does instruction on the nature of science and the nature of learning science need to be embedded in content, it also needs to be *explicit* in order to be effective [12]. Instruction that explicitly addresses these issues has been shown to be much more effective in improving students' views and attitudes about aspects of the nature of science and science learning than implicit approaches that use inquiry-based science activities but lack explicit references to the nature of science or issues in the nature of learning science [12]. For example, Elby [13] demonstrated that students enrolled in a curriculum that was "epistemologically-focused" showed significantly greater gains on the Epistemological Beliefs Assessment for Physical Science than did curricula focused on content only. Elby argued that "even the best curricula aimed at conceptual development *but not aimed explicitly at epistemological development* do not produce comparable epistemological results [13 p. S57]."

Several instruments have been developed to assess students' views of the nature of science and the nature of learning science. These include the Maryland Expectations Survey (MPEX) [14], the Epistemological Beliefs Assessment for Physical Science (EBAPS) [15], the Colorado Learning Attitudes about Science Survey (CLASS) [16, 17], and the Views of the Nature of Science (VNOS) survey [11]. While each of these instruments measures slightly different aspects of students' expectations, beliefs, and understandings of the nature of science and the nature of learning science, studies that use these instruments show remarkable similarities—students of all ages have difficulty learning how science knowledge is constructed and in most cases regress in sophistication as measured by these instruments over a semester-long science course. For example, Redish, Saul, & Steinberg [14] found that at six different schools, students' overall MPEX scores deteriorated over one semester of introductory physics rather than becoming more sophisticated. Although students enrolled in courses that use

research-based curricula show significant conceptual gains as measured by conceptual instruments such as the Force and Motion Conceptual Evaluation, they do not show significant increases in beliefs about aspects of the nature of learning science measured by the MPEX or the CLASS, and in fact show negative shifts on the CLASS [18]. These results suggest that conceptual learning is not necessarily associated with the development of expert-like thinking *about* the nature of learning science. Hrepic et al. [6] studied a curriculum designed specifically for pre-service elementary teachers, *Operation Primary Physical Science Curriculum (OPPS)*, from both the conceptual and attitudinal perspective. While significant conceptual gains were found using a conceptual instrument designed by the authors of the curriculum, only very small positive shifts in attitudes about science and the nature of science and the nature of learning science were measured by the CLASS and in one of three courses studied, CLASS scores deteriorated [6] over a single semester. Although the OPPS curriculum was developed for pre-service elementary teachers, it does not appear to explicitly address issues about learning science and the nature of science knowledge. Rebello and Mamolo [19] also studied a research-based curriculum designed specifically for pre-service elementary teachers. Students in this Learning Cycle-based course were given both the EBAPS [15] and VNOS [11] surveys. Neither survey showed significant shifts in students' overall scores on these instruments although the EBAPS showed a small positive shift in the Real-Life applicability category and the VNOS showed a small positive shift in the Inferential Nature of Models.

We hypothesized that the Physics and Everyday Thinking curriculum and the Physical Science and Everyday Thinking curriculum would show gains on an instrument that purports to measure attitudes about learning and students' views of the nature of science because both

curricula explicitly address these issues. The remainder of this paper will report on a study in which this hypothesis was investigated.

PHYSICS AND EVERYDAY THINKING

Physics and Everyday Thinking (formerly Physics for Elementary Teachers) and *Physical Science and Everyday Thinking* are inquiry-based curricula designed to meet the needs of elementary teachers. *Physics and Everyday Thinking* (PET) course content focuses on the themes of interactions, energy, forces, and fields. *Physical Science and Everyday Thinking* (PSET) is based on the PET curriculum but integrates significant chemistry content by focusing on PET themes plus atomic-molecular theory to account for physical and chemical changes, conservation of matter, and gas behaviors. Each curriculum consists of carefully sequenced sets of activities intended to help students develop physical science ideas through guided experimentation and questioning with extensive small group and whole class discussion. The curricula also include a series of *Learning About Learning* (LAL) activities, in which students are *explicitly* asked to reflect on their own learning, to reflect on the learning of other students, and to reflect on the learning of scientists. The LAL activities are embedded throughout the curricula, often occurring between two content-focused activities. For example, after PET students develop a domain-like model of magnetism through experimentation and consensus discussions, they read about the historical development of the domain model of magnetism and investigate how and why the scientifically accepted model of magnetism changed over time. PET and PSET students study their own learning by reflecting on how their ideas about a particular concept changed over time and what classroom activities, discourse, or experiments influenced these changes. Finally, PET and PSET students investigate the learning of others by watching short video clips of

elementary children struggling with scientific issues similar (but age appropriate) to those found in the PET/PSET curricula. The PET and PSET *Learning about Learning* activities are similar in format to the content activities and follow a guided-inquiry format. Each activity has three parts: (1) Initial Ideas, (2) Collecting and Interpreting Evidence, and (3) Summarizing Questions. Examples of the table of contents for Chapter 6 in PET and Chapter 4 in PSET are shown in figure 1. In figure 1, LAL activities are indicated with a ♦ symbol. PET Chapter 6 Activities 1 and 2 focus on children’s ideas, Activity 2 Homework focuses on PET students’ own ideas, and Activity 4 focuses on social scientists ideas about learning. In PSET, Chapter 4 Activity 3 homework focuses on children’s ideas, activity 4 focuses on students’ own ideas and how science ideas are represented by the computer simulator, and Activity 5 Homework focuses on the nature of science.

<p><u>PET Chapter 6: Light Interactions</u></p> <p>A1: Shiny Surfaces and Seeing</p> <p>A1 HW: Children’s Ideas about Light (reading) ♦</p> <p>A2: Children’s Ideas about Light and Vision ♦</p> <p>A2 Homework: Ideas about Learning Science ♦</p> <p>A3: Non-Shiny White and Black Surfaces</p> <p>A3 Homework: Refraction of Light</p> <p>A4: Light and Color</p> <p>A4 Homework: Social Scientists’ Ideas ♦</p> <p>A5: Explaining Light and Color Phenomena</p>	<p><u>PSET Chapter 4: Interactions & Gases</u></p> <p>A1: The Small Particle Model and Gases</p> <p>A2: The SPM and Gas Pressure</p> <p>A2 HW: Explaining Gas Pressure</p> <p>A3: Effects of Pressure Difference</p> <p>A3 HW: Children’s Ideas about Gases ♦</p> <p>A4: The SPM and Temperature</p> <p>A4 HW: The Small Particle Simulator ♦</p> <p>A5: Explanations Involving Gases</p> <p>A5 HW: The Nature of Science ♦</p>
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Figure 1. Table of contents of Chapter 6 PET and Chapter 4 PSET.

PET and PSET *explicitly* address issues about the nature of science and the nature of learning science through the LAL activities and these activities are embedded within the content instruction. Thus, it would be expected that students who participate in the PET and PSET curricula would be more likely to move toward expert-like thinking about the nature of science and the nature of learning science than students who participate in physics curricula that either

address the nature of science and science learning *implicitly* or do not attend to them at all. We investigated the hypothesis that students in PET and PSET courses would move toward expert-like thinking about the nature of science throughout one semester of taking PET or PSET by administering the CLASS instrument in multiple PET/PSET classroom settings.

Previous work using the EBAPS at one institution showed that PET and PSET students did indeed have higher positive shifts toward expert-like responses than students from traditional courses [20]. The EBAPS was administered pre/post to 228 students enrolled in traditional lecture format earth science and general physics courses and to 173 students enrolled in PET and PSET courses at a single university. Post-test composite scores were 14-25% higher for the students enrolled in the PET and PSET courses than for the students enrolled in the traditional courses. Furthermore, composite scores indicate a +7% to +18% change toward “expert-like” responses about the nature of science and learning for students enrolled in the PET and PSET courses, and a change of -2% to -9% for students enrolled in the traditional courses. In other words, the traditional students became more novice-like in their responses about the nature of science and learning during a semester of traditional instruction but the PET/PSET students became more expert-like in their responses. The trend towards novice-like responses over a single semester is commonly observed in science courses, even those that are based on research in science education. However, Elby [13] found overall gains as high as 5.3% on the EBAPS when he used curricula that were epistemologically focused.

In the following section we discuss the administration and analysis of the CLASS survey in PET/PSET courses. The atypical shifts found among students enrolled in PET/PSET may be the result of the intensive, explicit focus on issues of Learning about Learning embedded throughout the curricula.

METHOD AND DATA ANALYSIS

We administered pre and post CLASS surveys to 360 students enrolled in nine different PET and PSET courses at seven universities. These PET and PSET courses had enrollments ranging from 13 to 100 students. The CLASS was chosen for this study because it is worded to be applicable to a wide variety of physics courses and to be meaningful to students who have not taken physics [16]. A total of 288 pre-surveys and 265 post-surveys were returned. The conditions for the administration of the surveys were similar across universities. All were done online. Most were for extra credit and were done outside of class. Of the surveys returned, 182 were used for the analysis because they met the following criteria: the student submitted both pre and post-surveys, the student correctly responded to question #31 which is intended to catch students who are not reading the survey, the student did not select the same answer to almost all the statements which is an indication that the student did not read the survey, and the student answered all or almost all of the statements. Characteristics of each of these universities and courses are shown in Table I. One university offered three courses taught by two different instructors. Institutions ranged from community colleges to research universities and were located throughout the United States.

Table I. Characteristics of Schools and Courses

Course	School	Instructor	School Type	Region	Curriculum	Enrollment	Surveys Scored
1	A	S	Community College	Mid-Atlantic	PET	13	6
2	B	T	Community College	South	PET	30*	18
3	C	U	Research University	Midwest	PET	100	54
4	D	V	Regional University	South	PSET	32	18
5	D	W	Regional University	South	PSET	32	18
6	D	W	Regional University	South	PET	25	10
7	E	X	Technical University	South	PET	30	17
8	F	Y	Regional University	Midwest	PET	48*	20
9	G	Z	Regional University	Midwest	PET	50*	21

*Students in these courses were divided into two different sections.

The CLASS consists of 42 statements for which students are asked to agree or disagree using a 5-point Likert scale. Of these 42 statements, 36 are scored by comparing a students'

response to the expert response. Statement 31 is not scored but is used to eliminate some surveys as described above. The other five unscored statements lack an expert consensus and are being revised. An overall favorable score is then calculated for each student by comparing the percentage of answers in which their response matches the expert response. An average score for each course is then found by averaging all student scores. We used the standard CLASS scoring procedure reported in Adams et al. [16]. Most questions on the CLASS are categorized into at least one of eight categories, listed in Table II with a sample question.

Table II. Categories of the CLASS instrument with example questions

CLASS Category	Example Question (expert response)
Personal Interest	I think about the physics I experience in everyday life (agree)
Real World Connection	Learning physics changes my ideas about how the world works. (agree)
Problem Solving (PS) General	If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works. (disagree)
Problem Solving (PS) Confidence	Nearly everyone is capable of understanding physics if they work at it. (agree)
Problem Solving (PS) Sophistication	If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations. (disagree)
Sense Making/Effort	I am not satisfied until I understand why something works the way it does. (agree)
Conceptual Understanding (CU)	Knowledge in physics consists of many disconnected topics. (disagree)
Applied CU	When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values. (disagree)

RESULTS

Pre and Post CLASS scores for each participating course are shown in Table III along with the shifts for each course which from +4% to +16.5. Aggregate results from the CLASS study show an average shift of 8.8% in PET and PSET courses compared to average shifts of -6.1% to +1.8% found in other physical science courses (OPPS) designed especially for

elementary teachers with enrollments ranging from 14 to 22 students [6]. Interestingly, the PET/PSET courses with the largest pre-test scores had the smallest overall positive shifts. Courses with a statistically significant shift in average score from pre-test to post-test are indicated in Table III with an asterisk. A t-test was used to test for significance and to test the normality of each data set, an r-squared value was obtained for the data from each course by fitting a line to a plot of the theoretical Gaussian curve and the observed data points. R-squared values ranged from 0.82 to 0.99 so it is reasonable to report the standard error and p-value for each course, although the sample size was small in some cases.

Table III. Overall Favorable Scores on CLASS Survey (standard error in parentheses)

Course	Type	Enrollment	Curriculum	Pre-Test	Post-Test	Shift
1	Community College	13	PET	69.9 (2.6)	73.8 (4.2)	3.9 (3.6)
2	Community College	30	PET	53.6 (4.3)	67.0 (2.6)	13.3 (3.1)*
3	Research University	100	PET	51.6 (2.0)	58.3 (2.2)	6.7 (2.0)*
4	Regional University	32	PSET	49.5 (3.0)	59.0 (3.7)	9.5 (3.6)
5	Regional University	32	PSET	49.8 (3.7)	59.6 (3.8)	9.8 (2.8)
6	Regional University	25	PET	51.8 (2.7)	68.3 (3.3)	16.5 (3.8)*
7	Technical University	30	PET	51.6 (4.5)	62.1 (3.7)	10.6 (4.3)
8	Regional University	48	PET	64.2 (3.0)	70.4 (3.8)	6.3 (2.5)
9	Regional University	50	PET	55.0 (3.6)	63.1 (4.0)	8.1 (2.7)*
All Students				53.8 (1.15)	62.6 (1.18)	8.8 (1.1)*

* p -value < 0.05

The data from table III are re-represented in figure 2 with data from a study on second-semester, calculus-based, introductory physics courses taught in the same format at a single university [18]. The negative CLASS shifts shown for the calculus-based courses in figure 2 are representative of physics courses and are small in comparison to traditional courses. Each of the

calculus-based courses except Fa05 and F06 was taught by at least one faculty member who was experienced in methods supported by physics education research. Figure 2 highlights the difference in CLASS shifts among PET and PSET students in comparison to a transformed calculus-based course taught by different instructors [18].

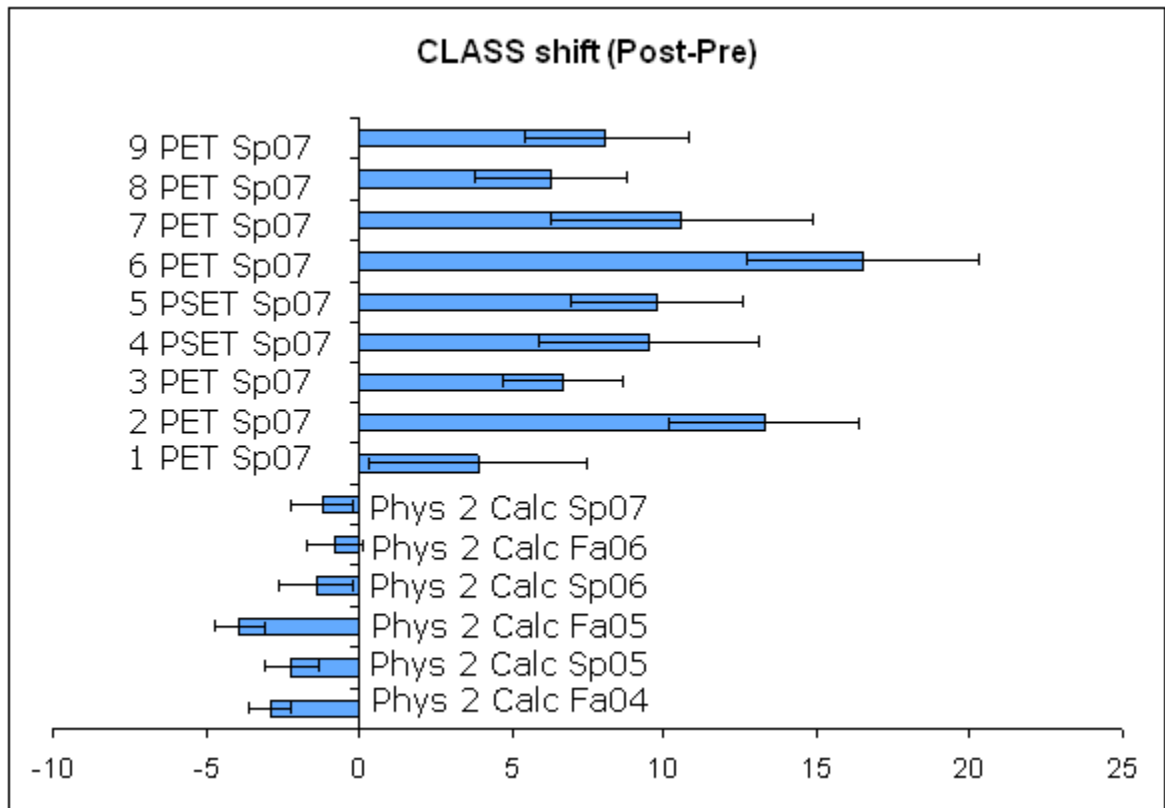


Figure 2. CLASS shifts for PET/PSET courses compared to calculus-based courses, PET/PSET courses are numbered to match corresponding data in table III.

Table IV shows comparisons of CLASS pre/post scores and shifts for different curricula and different instructional settings. As shown in Table IV, the average CLASS pre-test score is 54% for the PET/PSET courses which is lower than typical scores found in calculus-based courses. Traditional lecture style courses have been found to have shifts on the CLASS of -8.2% to +1.5% in calculus-based courses with enrollments of 40 to 300 students in each course

section. Shifts of 1.0% have been found in courses for non-science majors, and -9.8% in algebra-based courses for pre-med students [21]. Of the courses shown in table IV, only PET and PSET embeds activities that explicitly address the nature of science and the nature of learning science.

Table IV. Comparison of overall CLASS Scores for different courses.

Course	N	Pre	Post	Shift
PET/PSET	182	54%	63%	8.8%
OPPS Fa04*	14			1.8%
OPPS Sp05*	20			-6.1%
OPPS Fa05*	16			2.9%
Non-Sci Fa03	76	57%	58%	1.0%
Alg Fa03	35	63%	53%	-9.8%
Calc Fa03	168	65%	67%	1.5%
Calc Sp04	398	68%	70%	1.5%
Calc Fa03	38	65%	57%	-8.2%

* Pre and post scores were not reported for these courses

Recent research, has demonstrated significant positive shifts (4.6% - 11.7%) on CLASS scores in some *Physics by Inquiry* courses which have a strong implicit focus on the nature of science and the nature of learning science but do not explicitly address these issues [22]. The same study did not show positive shifts in other *Physics by Inquiry* courses investigated.

Figure 3 shows the PET and PSET CLASS scores according to the categories shown in Table II. The shifts in all categories except Sense Making/Effort and PS Confidence were significant at $p < 0.01$. PS Confidence was significant at $p < 0.05$. The highest shifts for PET/PSET students were made in the following categories: Personal Interest, Problem Solving Sophistication, Conceptual Understanding, and Applied Conceptual Understanding. These categories are similar to one another but have subtle differences. Overall, these categories assess students' beliefs about the structure of knowledge (i.e. is it a set of isolated facts handed down from authority or connected concepts that should make sense to the learner?) These categories also assess a students' views on the extent to which one's conceptual understanding (in contrast

to formulaic manipulation and memorized facts) can and should be used in the process of solving physics problems.

In the post survey, students were asked additional questions about their interest in physics using the following questions:

- At the start of the term what was your level of interest in physics? (low, moderate, high)
- Currently what is your level of interest in physics? (low, moderate, high)
- During the semester, my interest in physics (increased, decreased, stayed the same)

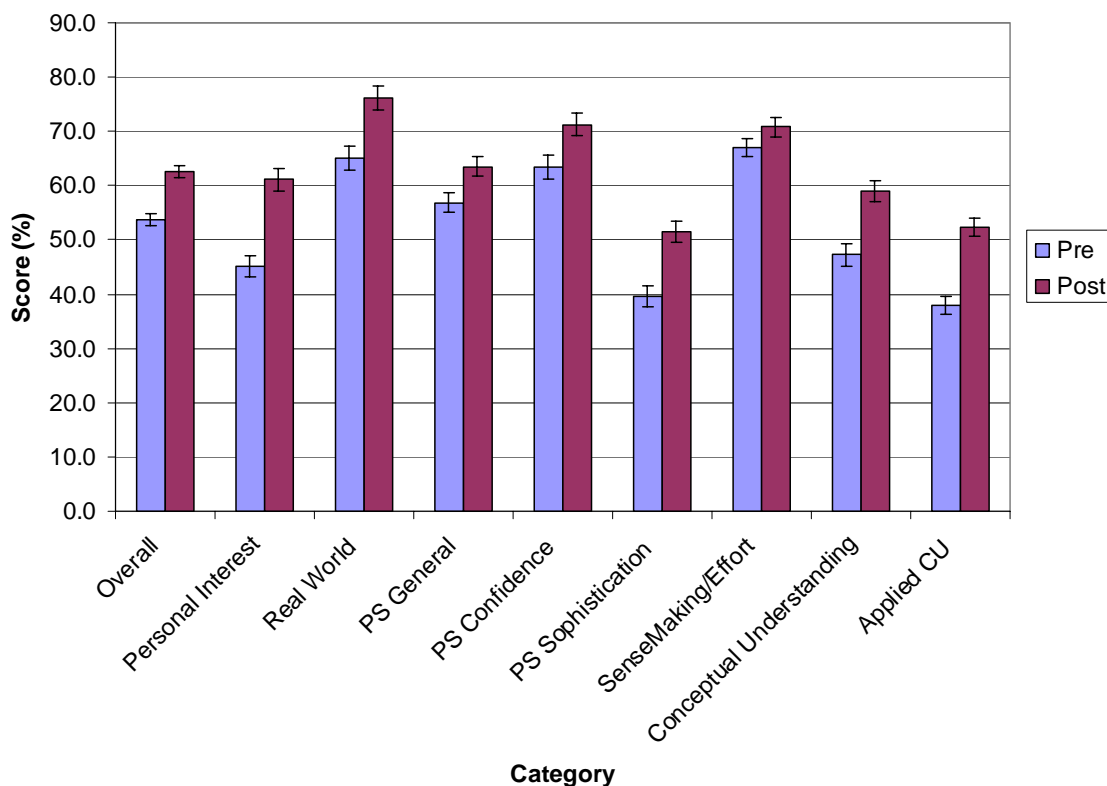


Figure 3. PET/PSET CLASS scores by category

In response to these questions 59% of PET/PSET students rated their interest in physics as low when they began the course, while only 21% rated their current interest as low at the end of the

semester as shown in Figure 4(a). Sixty-six percent of these students said that their interest in physics increased during the semester. In a study involving a more traditional calculus-based physics course, Perkins et al. [21] found an increase of only 19% and a decrease of 45% on the same questions (shown in Figure 4(b) for comparison). As is shown in the two graphs in Figure 4, the PET and PSET curricula seem to have the opposite effect of the calculus-based course shown.

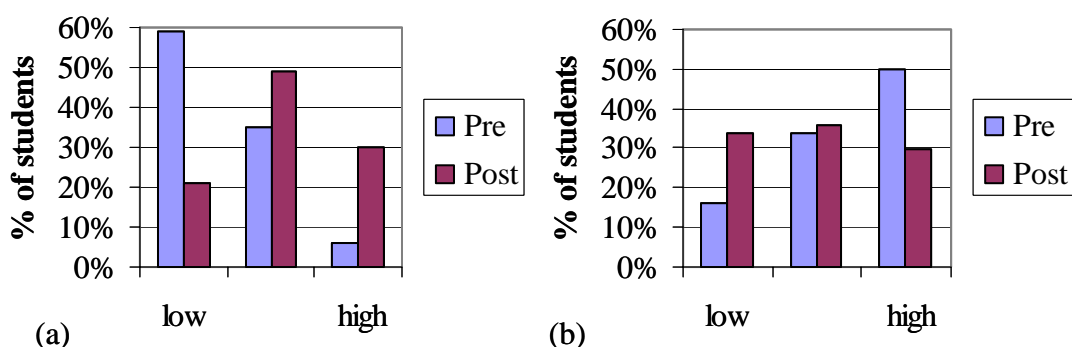


Figure 4. Personal Interest in Physics in (a) PET/PSET and (b) Calculus-Based course

The questions associated with the categories of Personal Interest, Problem Solving Sophistication, Conceptual Understanding and Applied Conceptual Understanding seem to be related and interdependent as viewed by the students. For example, in a previous semester, PET students were asked *why* they stated that their interest in physics increased, decreased, or stayed the same. Some representative statements are listed below.

“This class showed me how to solve physics problems on my own taking into consideration my own experiences. I learned that physics is not scary nor is it ALL complicated. Many of the problems and the demonstrations of how things work turned out to be very simple. I loved the way the class was taught - I learned everything through discussions and exploration and discovery.”

“This class showed me how cool physics can be....cool in the sense that physics is such a huge part of my life....and cool in the sense that I feel like I have a solid understanding of the topics we explored.”

“It was like the "blindness" were removed. I feel like I look at the world around me totally different than I did before. I now look at situations or scenarios and try to explain or make sense of them scientifically rather than accepting them at face value.”

As is suggested by the representative statements above, interest in physics appears to be associated with the students redefining what physics problems are, how problem-solving relates to the self, and that physics is not scary and foreign but a part of one’s everyday life.

These students were also asked why their confidence in taking a future physical science course increased, decreased, or stayed the same. The following answers are representative.

“I can see now that physics is more than just solving equations. The concepts are much more important. I can use this to help think about difficult problems.”

“I feel like I could at least try to figure out any physics problem that was put before me. I may not solve it but I would at least know how to tackle it.”

“I understand the concepts behind the mathematical equations. I can now build on this understanding. Prior to this class, I memorized bits of information and equations/vocabulary but did not truly understand the concepts represented in them.”

These statements suggest that students’ confidence in solving physics problems might be tied to their recognition of problem solving as involving concepts that these students came to believe could be understood. These students seem to be explicitly aware that solving physics problems conceptually is more than just the stating memorized facts and vocabulary.

CONCLUSIONS AND IMPLICATIONS

The answers PET and PSET students gave in the CLASS pre surveys suggested that they were thinking about solving physics problems as the process of arriving at a pre-determined answer through formulaic manipulation and memorization. Their answers on the post surveys suggest that the students were now thinking about solving physics problems as the process of *making sense* of physical phenomena. In all PET and PSET activities, students are expected to first express their initial ideas about a physical phenomenon, then engage in an experiment or manipulate apparatus to collect and interpret evidence, and finally they answer summarizing questions designed to help them make inferences from their data. This learning sequence is different from what they might have experienced in other high school or college-level physics courses that rely on lectures and note-taking. It seems that the experience of working with apparatus and generating explanations in small and large groups has allowed the students to obtain a more personal connection to the content of the course. We conjecture that in a sense, students in PET and PSET classes *redefined* for themselves what it means to solve problems in physics.

The conceptual nature of the course alone could have led to the atypical positive shifts on the CLASS found in this study. However, Akerson et al. [12] and Elby [13] have argued that explicit instruction on the nature of science and on the nature of learning is necessary if we expect to see students make these types of gains. Abd-El-Khalick [11] further argued that this type of instruction must be embedded in content-focused instruction. While the PET and PSET curricula have all of these elements, further work is needed to distinguish the effects of the conceptual focus of the curriculum, the explicit instruction on the nature of science and the nature of learning science, and the fact that the explicit instruction is embedded within the

content. Regardless of the causal variable or combination of variables, this study has demonstrated that the PET and PSET curricula are effective in creating positive shifts among non-science majors in their responses to the CLASS survey.

A large portion of the students who enroll in a PET or PSET course are prospective and practicing elementary or middle school teachers. Future and practicing teachers must develop positive views of science since their views will greatly influence the views of their students. Elementary teachers are often the first representatives of the science community with whom young children come into contact. These teachers can encourage or discourage their students from scientific inquiry or they can avoid the topic of physical science altogether. The PET and PSET curricula seem to help prospective and practicing teachers enrolled in the courses develop confidence in their ability to do and teach physical science. Students enrolled in these courses appear to learn to see themselves as involved in personal sense-making when they are engaged in the problem solving process. In doing so, they develop more sophisticated views of the nature of science and the nature of learning science. This is a central goal of scientific literacy for the general public.

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