

Learning to Think Like Scientists with the PET 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 shift away from scientist-like views of the discipline (and views of learning within the discipline) and toward novice-like views. Shifts toward scientist-like views are found when course materials and instruction explicitly address epistemology, the nature of science, and the nature of learning. 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 science learning. We show that in PET courses with small and large enrollments, shifts toward scientist-like thinking 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

National documents have made clear the need for increased scientific literacy among the general public [1] [2]. Among the issues raised in these types of reports 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. Science education 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], Operation Primary Physical Science [5], Physics and Everyday Thinking [6], and Physical Science and Everyday Thinking [7]. In most cases, large conceptual gains have been found to be associated with these specialized curricula [5][8][9]. However, less work has been done to determine how students' beliefs about learning science and their understanding of the nature of scientific knowledge are impacted by such courses.

Research has consistently demonstrated that K-12 teachers and their students do not develop desired understandings of the nature of science and the nature of science learning [10]. Abd-El-Khalick showed that pre-service elementary teachers developed a better

understanding of certain aspects of the nature of science when nature of science instruction was embedded within content instruction [10]. Unfortunately, few science teacher education courses focus on content and few science courses focus on the nature of science and the nature of learning science.

Research has found that not only does instruction on the nature of science and the nature of learning need to be embedded in content, it also needs to be *explicit* in order to be effective [11]. Instruction that explicitly addresses issues about the nature of science and learning is 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 knowledge and learning [11]. For example, Elby [12] demonstrated that a curriculum that was "epistemologically-focused" had greater success in helping students develop sophisticated beliefs about the nature of science knowledge than 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 [12]."

Several instruments have been developed to assess students' views of the nature of learning science and their views of the nature of science knowledge. These include the Maryland Expectations Survey (MPEX) [13], the Epistemological Beliefs Assessment for

Physical Science (EBAPS) [14], the Colorado Learning Attitudes about Science Survey (CLASS) [15], and the Views of the Nature of Science (VNOS) survey [10]. 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 over a semester-long science course. For example, Redish, Saul, and Steinberg [13] 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 the nature of science or the nature of science learning as measured by the MPEX or the CLASS [16]. These results suggest that conceptual learning is not necessarily associated with expert-like beliefs about the nature of learning science. Hrepic et al. [5] 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 knowledge and learning were measured by the CLASS and in one course CLASS scores deteriorated [5]. 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.

THE PET AND PSET CURRICULA

Physics and Everyday Thinking (PET-formerly Physics for Elementary Teachers) and Physical Science and Everyday Thinking (PSET) are inquiry-based curricula designed to meet the needs of elementary teachers. PET course content focuses on the themes of interactions, energy, forces, and fields. PSET is based on the PET curriculum but integrates significant chemistry content by focusing on the same 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* activities, in which students are *explicitly* asked to reflect on their own learning, the learning of other students, and the learning of scientists. The *Learning about Learning* 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.

PET and PSET *explicitly* address issues about learning science and the nature of science knowledge 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 participated 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 scientific knowledge 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 thinking than students from traditional courses [17]. 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. Composite scores indicate a +7% to +18% change toward "expert" thinking about the nature of knowledge 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. Furthermore, 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. In other words, the traditional students became more novice-like in their thinking about the nature of knowledge and learning during a semester of traditional instruction but the PET/PSET students became more expert-like in their thinking.

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 [15].

A total of 288 pre-surveys and 265 post-surveys were returned. 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, and the student answered all or almost all of the statements.

Characteristics of each of these universities and courses are shown in Table 1. One university offered three courses taught by two different instructors.

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

RESULTS

Pre and Post-CLASS scores for each participating course are shown in Table 2 along with the shifts for each course.

TABLE 2. Overall Favorable Scores in Pre/Post CLASS Survey (standard error of the means in parentheses)

| Course | Pre-Test | Post-Test | Shift |
|--------------|-------------|-------------|-------------|
| 1 | 69.9 (2.6) | 73.8 (4.2) | 3.9 (3.6) |
| 2 | 53.6 (4.3) | 67.0 (2.6) | 13.3 (3.1)* |
| 3 | 51.6 (2.0) | 58.3 (2.2) | 6.7 (2.0)* |
| 4 | 49.5 (3.0) | 59.0 (3.7) | 9.5 (3.6)* |
| 5 | 49.8 (3.7) | 59.6 (3.8) | 9.8 (2.8) |
| 6 | 51.8 (2.7) | 68.3 (3.3) | 16.5 (3.8)* |
| 7 | 51.6 (4.5) | 62.1 (3.7) | 10.6 (4.3) |
| 8 | 64.2 (3.0) | 70.4 (3.8) | 6.3 (2.5) |
| 9 | 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

Shifts toward favorable increased from +4% to +16.5%, which is similar to the shifts found by Allen and Kruse on the EBAPS. 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 [5].

Table 3 shows comparisons of CLASS pre/post scores and shifts for different curricula and different instructional settings. As shown in table 3, the average CLASS pre-test score is 54 which is low in comparison to 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.

TABLE 1. 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.

TABLE 3. Comparison of overall CLASS Scores for different courses.

| Course | N | Pre | Post | Shift |
|--------------|-----|-----|------|-------|
| PET/PSET | 189 | 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

Shifts of 1.0% have been found in courses for non-science majors, and -9.8% in algebra-based courses for pre-med students [18]. Of the courses shown in table 3, only PET and PSET embeds activities that explicitly address the nature of science and the nature of learning science. Recent research however, has demonstrated significant positive shifts on CLASS scores in 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 [19].

CONCLUSIONS

The PET and PSET curricula showed large positive shifts on the CLASS compared to other courses. Akerson et al. [11] and Elby [12] have argued that explicit instruction on the nature of science and learning is necessary if we expect to see students make gains in these areas. Abd-El-Khalick [10] has argued that this type of instruction must be embedded in content-focused instruction. Our data support these arguments although further work is needed to distinguish the effects of the “explicit” variable and the “embedded within content” variable. Future and practicing teachers must develop positive views of science since their views will greatly influence the views of their students. Our results suggest that the PET and PSET curricula helped non-science majors become more expert-like in their thinking about the nature of science and learning science.

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