Physics By Inquiry: Addressing Student Learning and Attitude

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Abstract. In the last decade, the results of Physics Education Research and research-based instructional materials have been disseminated from traditional research universities to a wide variety of colleges and universities. Nevertheless, the ways in which different institutions implement these materials depend on their students and the institutional context. Even with the widespread use of these curriculums, the research documenting the effectiveness of these materials with different student populations is scarce. This paper describes the challenges associated with implementing *Physics by Inquiry* at California State Polytechnic University Pomona and confirms its effectiveness in promoting student conceptual knowledge of physics. However, despite the positive effect on student learning, the evidence suggests that the students did not appreciate the self-discovery aspect of the inquiry approach and characterized the learning process as difficult and unpleasant.

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INTRODUCTION

Teaching by inquiry emphasizes the process of science rather than lecturing and explaining facts. The inquiry process includes: observing, measuring, predicting, inferring, using numbers, defining operationally, formulating hypotheses, interpreting data, controlling variables, experimenting and communicating. Teaching is accomplished by guiding students through carefully sequenced experiments and exercises designed to help them develop a functional understanding of the concepts. Research supports the efficacy of inquiry models in enhancing student performance and skill development [1]. However, much less is known about the effectiveness of the inquiry method with different population of underprepared students and its impact on student attitude.

This paper describes the implementation of the *Physics by Inquiry* [2] (PBI) involving underprepared students at Cal Poly Pomona (CPP). A research-based pre/post-test design was used to investigate the effectiveness of the inquiry approach involving topics of the *Properties of Matter* module. In addition, Lawson's classroom reasoning test [3] was administered to measure the student level of formal reasoning. The results and associated challenges are discussed as well as the influence on student attitudes and expectations.

COURSE & POPULATION

This study involved pre-service teacher education students in the first of a three-quarter required science course at CPP. The original physical science course had separate lecture and laboratory components. To implement the inquiry approach, the lecture and laboratory were combined; students met twice a week for a total of six hours. The classroom setup was a typical physics laboratory with fixed tables that hindered group discussion and checkout activities. The course focused on the topics of *Properties of Matter* and *Heat & Temperature* using the *Physics by Inquiry* textbook. There were fifteen students in the class, mostly female, liberal art majors with an interest in an elementary school teaching career. Most of the students had little or no physics or physical science background. None of the students had experienced a formal inquiry-based learning experience prior to this course.

DATA

Students completed a set of open-ended pre-test questions on each topic prior to instruction on relevant module [4]. The post-test data on student conceptual performance were collected from three exams over the course of the quarter. The results indicate reasonable improvement in the students' understanding of material, which lends further support between the

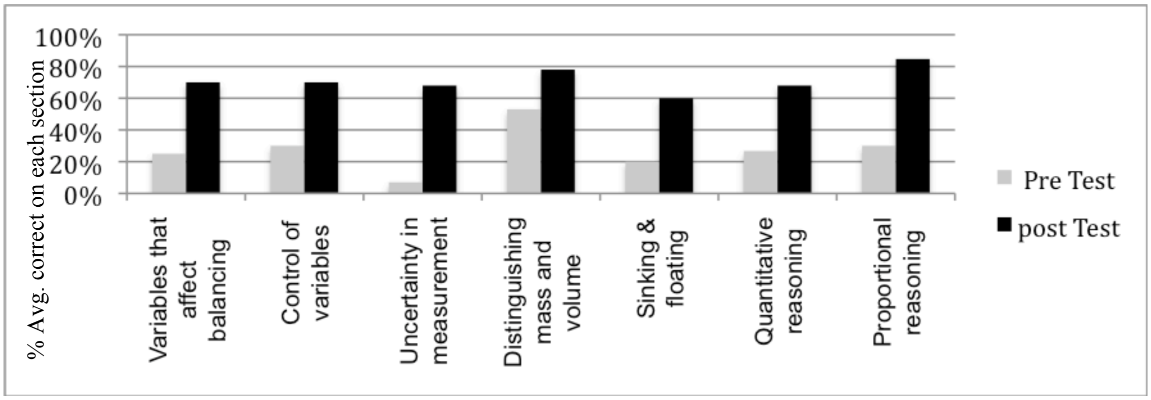

FIGURE 1. Student pre/post-test data at Cal Poly Pomona on different topics of Properties of Matter, each test contained several related questions.

inquiry method and the enhanced conceptual understanding described in the literature [See **FIGURE 1**].

Further analysis of the pre-test data confirmed that the students had little background knowledge related to the course. For example, the average correct answers on the questions related to measurement uncertainty was only 7%, and on questions related to sinking and floating, only 20% of the responses reflected correct understanding of these physical principles. The students' written explanations often did not reflect consistent and logical thought patterns that would have enabled them to propose relationships between observed phenomena. Most students often restated their original answer as their reasoning and did not use scientific reasoning to predict logical consequences, to weight evidence, and to justify a particular conclusion.

The learning gain in the content knowledge for each topic was measured by calculating a normalized gain score. Normalized gain is the ratio of the actual gain [(post-test score)% – (pre-test score)%] to the maximum possible gain [100% – (pre-test score)%] [5]. The observed gain across all topics was reasonably high (more than 50%) [See **TABLE 1**].

In addition to open-ended pre-test questions, Lawson's classroom reasoning test was administered (only once at the beginning of the course) to assess the students' formal reasoning skills. Consisting of 24 multiple-choice questions, the sequence of the questions suggests reasoning for the previous answer. In order to earn one (1) correct answer, students must select the correct response AND the correct reason; hence, the maximum test score is twelve (12). Most of the students (85%) earned less than seven (7) points on the test and did not show strong evidence of a formal level of reasoning ability. The percentage of student correct responses to some of the different concepts is summarized in **TABLE 2**.

Even though students performed very well on questions related to conservation of mass and displaced volume (86% correct), their proportional reasoning and control of variable scores were very low and consistent with the open-ended conceptual pre-test data. Moreover, a majority of the students answered incorrectly the questions designed to test Hypothetico-deductive reasoning; their answers lacked the formal reasoning ability needed to make inferences of particular instances from a general law or to use the consequences of hypotheses to evaluate the validity of the hypotheses themselves.

STUDENT FEEDBACK

Students often show some resistance towards any innovation, especially when the new structure demands more effort. Thus, explaining the process and the potential benefits of the learning by inquiry at the beginning of the quarter was important. A discussion of the philosophy behind teaching by questioning and value of self-discovery was necessary in order to encourage the students to assume control of their own learning.

To gauge the students' experience, a three-item open-ended mid-quarter assessment tool was administered on the forth week of the quarter. The items were: (1) what is helping you learn the material

Topics of Properties of Matter	Pre-test	Post-test	Normalized Gain
Variables that affect balancing	25%	75%	67%
Control of variables	30%	75%	64%
Uncertainty in measurement	7%	60%	57%
Distinguishing mass and volume	53%	90%	79%
Sinking & floating	20%	60%	50%
Quantitative reasoning	27%	75%	66%
Proportional reasoning	30%	80%	71%

TABLE 1. Normalized gain for students in different topics of Properties of Matter

in this class; (2) what makes learning hard in this class; and, (3) what other suggestions do you have to improve your experience in this class?

The students' responses to question one indicate that most students seem to value the group work and the hands on approach:

> *"The group involvement is what really helps."*

> *"What has helped me to learn the material is all the hands-on experiments."*

> *"Going through the labs and sharing ideas with a partner is helping my learning of the material."*

However, students generally seemed to dislike the self-discovery aspect of the inquiry curriculum and that teaching occurred by questioning rather than by telling:

> *"I think that not all of the class should be learning by inquiry and that we need a good portion of lecture. People learn in different ways and I need some lecture and teacher explanation, not my blind ides going into a exercise."*

> *"Not lecturing before we start the experiments makes it hard to understand what it is we are supposed to be finding."*

> *"The things make learning hard is that the teacher doesn't lecture, also if the concepts of what we are learning is not demonstrated to me prior to doing the section, it is a lot harder (to learn).*

Students collectively suggested that they "*need more lectures"* and that the instructor should tell them "*what they need to know*." In the final course evaluation, the overall attitude was somewhat more positive, but some student comment shared the same nature. One of the stronger students stated:

> *"It was unfair that I had to do all the explaining myself and also help others to understand."*

DISCUSSION

While the research data shows reasonable improvement in student understanding of the course topics and supports the inclusion of inquiry models in post-secondary science classrooms, the students' self-reported attitudes and expectations conflict with observed learning gains. The results of this study suggest a serious disconnect between student satisfaction and learning; students learned the content well but disliked the process.

Different Concepts & Reasoning Levels	% Correct
Conservation of mass	86%
Conservation of displaced volume	86%
Proportional reasoning	30%
Control of variables	15%
Hypothetico-deductive reasoning	7%

TABLE 2. Lawson's Classroom Reasoning Test results

The results describe the reluctance of students to develop an appreciation for the self-discovery process inherent in the inquiry approach. To address this reluctance, student previous experiences and knowledge background must be recognized and incorporated into the course. The student responses to the attitude assessment indicate that many students found the process very difficult. There may be a variety of factors behind this finding. For example, the students did not have experience with inquiry-based teaching models in their high school and college courses; therefore, their unfamiliarity created an obstacle that impeded their ability to ease through the curriculum.

In addition, the data from the Lawson test suggest that most of the students had difficulty with scientific reasoning skills, where PbI relies on these skills heavily. The learning process was designed so that the students were forced to confront difficult conceptual ideas and to go through the reasoning process that was necessary to construct their own understanding, to draw generalizations, and to clarify the observed principles in an iterative fashion. Students in this population did not enjoy facing these challenges. Demanding facts and principles in a lecture presentation suggest a lack of comfort and their unwillingness to construct their own knowledge. The instructor's anticipation of this perspective by creating an awareness of the challenges at the beginning of the course did not seem to help students develop an appreciation for the self-discovery learning process.

Perhaps a serious re-examination of the traditional pedagogical assumptions and approaches is needed: being an effective learning process is not sufficient; an effective learning process should also be appealing to students. Finding ways that make the process of inquiry more natural, attractive, and interesting to students is one option. What innovative methods can improve student engagement with the self-discovery process and promote their interest and appreciation? Does employing advanced technology and use of simulations and virtual manipulation [5] enhance the appeal of the process? Should our education put even greater emphasis on inquiry-based learning through grade school and college to familiarize students with the process? Should the *Physics by Inquiry* curriculum further parse the reasoning gaps into even smaller steps for underprepared students? These unanswered questions require future research.

In spite of these issues, the evidence suggests that inquiry-based models of learning are viable and should be part of the science teacher's repertoire. Implementation of inquiry-based teaching and learning needs to account for factors such as the student's reasoning ability, background,, attitudes, and expectations.

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