Title: Understanding the Nature of Science and Nonscientific Modes of Thinking in Gateway Science Courses

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Background:

Many novice science learners view science as loosely connected pieces of information to be separately learned, in contrast to the web of meaningful interconnections perceived by science experts (diSessa, 1988; Hammer, 1989, 1994; Hammer & Elby, 2002; Sandoval, 2005). It has been long established that closing the novice-expert gap is one of the most difficult tasks in science teaching (Chi, Feltovich, & Glaser, 1981; Discenna, 1998; Kohl & Finkelstein, 2007; Slotta, Chi, & Joram, 1995; Winter, Lemons, Bookman, & Hoese, 2001). Moreover, this gap is not necessarily reflected by students' science grades or their ability to solve standard end-of-chapter problems (Mazur, 1997a, 1997b). It should not be surprising that teacher-centered instructional methods, such as lectures, are largely ineffective in helping students acquire expert-like science skills and behaviors (Hake, 1998; Mazur, 2009, 2010) and appreciate the nature of science (Buffler, Lubben, & Ibrahim, 2009; Ibrahim, Buffler, & Lubben, 2009; Kalman, 2009). Students' beliefs about the nature of knowledge and knowledge acquisition, namely, epistemic beliefs, are proved to affect their attitudes about science and science learning processes (Baumert et al., 2000; Edmondson & Novak, 1993; Lising & Elby, 2005; Songer & Linn, 1991; Tsai, 1999; Urhahne & Hopf, 2004). Furthermore, nonscientific modes of thinking developed by many undergraduates have a negative effect on their interest and motivation (Deslauriers, Schelew, & Wieman, 2011; Perkins, Adams, Pollock, Finkelstein, & Wieman, 2004), thus preventing many capable students from persevering with science and engineering careers (Seymour & Hewitt, 1997). In relying solely on lecturing in science courses or using some techniques, such as group activities as a bag of tricks "for enhanced teaching", faculty members do not promote a holistic approach to science learning, thus preventing students from experiencing science as an important human intellectual adventure. Part of the reason for student difficulties is that for a student taking a science gateway course, the language and epistemology of science are akin to a foreign culture (Kalman, 2011). Textbooks appear to be written in English and seemingly all that is required of the student is to understand the meaning of some scientific vocabulary. Moreover, science learning approaches based mainly on memorization that have often worked for students in high school, where the emphasis may have been largely on absorbing factual information, will fail them during more concept-oriented university gateway science courses (Slavin, 2007). The discrepancy between the personal epistemologies the students bring to their undergraduate science courses and scientific epistemologies that they need in order to succeed in science courses is one of the major problems in undergraduate science teaching. Therefore understanding students' epistemologies and helping them move along the novice-expert scientific epistemology continuum is an important element in improving undergraduate science learning. Additionally, there is a meta-language to talk about science - terms like theory, experiment, data, hypotheses, test, model or analogy - that should be explicitly discussed while science is taught and learned. Ideally, we want to create a learning environment in which students can not only succeed in undergraduate science courses, but also develop critical thinking and other transferrable skills vital for participation in a modern society.

Study Objectives:

The purpose is to see if the student has acquired a holistic approach to the subject and has learnt to look beyond what is close at hand- not in order to look away from it, but to see it better within a larger whole and in truer proportion. Strategies to help students acquire a holistic approach to the different elements of the course, to be aware that there can be many ways of looking at science phenomena and that only experiment, not logic, can be the determining factor in deciding which conceptualization is valid. These strategies include the Reflective Writing Tool, the Conceptual-Conflict Collaborative Group activities and the Critique Writing exercises. The in-class collaborative group exercises were designed to produce the learning environment for students to question their alternative personal scientific conceptions. The critique activity was introduced to promote critical examination of the alternatives produced in the collaborative group exercise. It is basically an argumentative essay in which students have to put forward as many possible arguments in favor of all the conceptual viewpoints raised in class and then point out which viewpoint is correct from an experimental point of view. All of these activities have been previously evaluated as stand-alone interventions. Each one of these courses lasted for one semester (13 weeks) and ranged from a relatively small (N=32 students) to a large course (N=100 students). The courses used different textbooks and had different formats. By conducting this research in a variety of introductory physics courses we are looking at evidence for common changes in students' epistemologies due to the study interventions.

Method:

The study is a three-year long research project. The first year of the study (2010-2011) consisted of two parallel pilot projects conducted in a single country. During the 2011-2012 academic year the study will be expanded to three institutions in that country and institutions in four other countries. During pilot testing two sections at each institution were taught by the same instructor. The experimental group was exposed to all of the activities and the control group was only asked to perform summary writing of textual material before coming to class. The study examines the scientific epistemologies of the students before and after they have experienced the above-mentioned interventions. It employs a mixed design approach combining quantitative (pre and post tests and student writing products) and qualitative data (interviews). Rubrics have been designed to examine reflective writing, critiques and interviews that are later subjected to qualitative analysis. The interviews probe students' epistemic beliefs, and their views about and the nature of science, whether their views have changed, and, if they have, the students are asked what brought about these changes. These interviews are videotaped and transcribed.

For pre- and post-tests of the scientific epistemologies respectively, we used the Lawson Test of Scientific Reasoning (A. Lawson, 1978; A. E. Lawson, 1992, 1996) in the pilot studies and are using *Discipline-focused Epistemological Beliefs Questionnaire* (Hofer, 2000) in the next phase. For the physics content test we used the enhanced version of the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992). The FCI is designed not as a test of intelligence, but as a probe of belief systems about mechanics and has been administered at a large number of universities from Arizona State University to Harvard and internationally. All of these instruments have been validated with the intended population. At the end of the course the same Final Exam was administered in both sections.

Preliminary Results:

The Final Exams scores between the experimental and control groups have been compared. No significant differences have been found in this analysis. Next the General Linear

Model (GLM) analysis has been performed on the data. The results of the GLM analysis revealed that the Final Exam scores depend on the pre-FCI scores and on the teaching method. Lawson pre-test has not been found to have a significant impact on students' Final Exam score. We found that controlling for the pre-FCI scores and Lawson pre-test, the experimental teaching method has been found to have a significant positive impact on students' Final Exam scores. The independent variables (pre-FCI and teaching method) explain about 36% of the Final Exam variance.

Based on the preliminary data, we have designed rubrics for analyzing the student writing products and interviews. These were designed using a mix of grounded theory and our experience using the activities over many years. Various versions of the rubrics were analyzed by the research team and applied to the writing products over an extended period until a final version emerged. The rubric for reflective writing involves 8 categories with increasing levels of competence and the rubric for the critique involves 4 categories again with increasing levels of competence. The interview rubric at this time [August 2011] is still under development. It currently has 8 levels, some with sublevels. In the analysis of the students' writing products, such as reflective writing and critiques, we focus on students' ability to identify main concepts and relationships between them, to look beyond a specific chapter, to identify conceptual difficulties they are having with the material. The following excerpt is a Reflective writing example of a student:

> *The theoretical content of this chapter is not all that different from chapter seven and fairly straightforward. It is more of a merging of the concepts of energy with more familiar problem solving strategies… To me, a deceleration caused by kinetic friction of, say, 10 m/s^2 would produce an enormous amount of heat. I have never thought about where that energy goes till now. My first reaction was that the tire would not be able to handle that amount of energy transfer, which I now know must be false... What I still do not understand is if the capacity of brake pads to absorb heat is higher than I expected, or rather if the rate at which deceleration translates to heat is much lower (Student D.P., Chapter 8 reflection).*

Excerpt from a post-interview with a student:

> Question: Now that the course is almost over, were your expectations fulfilled or did the course demand something different from you as a learner?
> *Student: Well, I didn't have any expectations of the course but one thing I've been thinking over and over again is things like observable phenomena, like what happens when the ball swings or falls and electric circuits, and this is the first physics course I've taken. So over and over again as I'm taking this course I'm thinking, oooh so that's how it's done… Because it's the things that I've seen in my life and see them every day but never thought about them and how they occur, how it's studied scientifically…. Another thing I noticed is that if I had taken it earlier, then it would have helped with my 2nd year calculus class last term... I now know that there was a lot of assumed knowledge in the course that I didn't have…*

Both the interviews and the student writing product indicate that students who were part of the intervention groups have undergone a shift in their thinking about physics and physics learning. Moreover, a number of them indicated how the skills they gained in the course could be transferred to other subjects. Writing products and interviews with the students from both control and experimental groups will be analyzed in detail and presented at the NARST conference.

Scientific Significance:

Our preliminary examination of the interviews and student writing products indicates that students in the experimental groups do change their way of thinking about science and the nature of science. Moreover, the way they approach studying physics indicates that the students change their way of learning due to their exposure to these activities**.** We also have some indication that students' change of learning strategies may transfer to other subjects. Thus the results of the study may have significance beyond science and will be of interest to a larger audience.

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