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A PRACTICAL DILEMMA: HIGH SCHOOL STUDENTS' PHYSICS-RELATED PERSONAL EPISTEMOLOGY

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ABSTRACT: This case study explores students' physics-related personal epistemologies in school science practices. The school science practices of nine eleventh grade students in a physics class were taped over six weeks. The students were also interviewed to find out their ideas on the nature of scientific knowledge after each school science practices. Analysis of transcripts yielded several themes which characterize students' ideas about the scientific knowledge in their school science practice. The findings show that students believe that scientific data should be accurate; yet, while they collect data, they can make mistakes that do not change the conclusion of experiments. Traditional, formulation-based, physics instruction might have led students to view physics knowledge as unchanging and isolated pieces of facts, and physics problems as having one single answer. Future implications and directions are discussed.

Keywords: Personal epistemology, case study, science practices

INTRODUCTION

Personal epistemology (PE) is defined as what individuals believe about what counts as knowledge, and how knowledge is constructed and evaluated (Hofer, 2008). Therefore, examining students' PEs helps us understand how students evaluate new information, and make fundamental decisions (Hofer, 2001).

Some researchers have argued that students' PEs are tacit and complex, (e.g., Kelly, 2008). Cultural, curricular, and social contexts are considered as important elements interweaving students' PEs (Sandoval, 2009). Some researchers have suggested examining students' school science practices may be an appropriate way to shed light on the complexity of students' PEs (Elby & Hammer, 2010; Sandoval, 2005). Students' practices in school science may reflect their tacit beliefs about the nature of knowledge, the methods by which knowledge is produced, and how it is evaluated (Metz, 2011; Sandoval, 2009). However, there are few studies that have examined students' PEs through students' school science practices (Metz, 2011, Yang & Tsai, 2012). Thus, there is a need to examine how the ideas about the nature of scientific knowledge are interpreted in the social and cultural contexts in schools.

Two perspectives have been used to examine individuals' epistemologies. One perspective is psychological, which views epistemology or beliefs in knowledge as personal, empirical, and contingent (NRC, 2007; Kittleson, 2011). The other perspective is social, which views the beliefs in knowledge as situational and context-dependent (Kelly et al., 2012; Yang & Tsai, 2012). The studies that consider both of these perspectives are rare. Investigating students' PEs from these two perspectives at the same time will help us draw a better picture of the students' ideas about scientific knowledge.

THEORETICAL MODEL

Hofer and Pintrich (1997) define PE as epistemic theories in four identifiable dimensions: (a) *the certainty of knowledge* -focused on the perceived stability and the strength of supporting evidence, (b) *the simplicity of knowledge* -the relative connectedness of knowledge, (c) *the justification of knowledge* -how individuals proceed

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to evaluate and warrant knowledge claims, and (d) *the source of knowledge* -knowledge resides as an external source or is constructed by learners.

LITERATURE REVIEW

Interviews and surveys are the most popular instruments to probe students' PEs from the psychological perspective in science education research. However, often the questions asked in interviews and surveys are about the nature of scientific knowledge in general and they are decontextualized and abstract (Samarapungavan, Westby, & Bodner, 2006). Some researchers argue that it may be misleading to attribute a particular stance to an individual (Hammer et al., 2005). Furthermore, there is evidence that students' epistemic reasoning is inconsistent across contexts (Driver et al., 1996; Leach et al, 2000; Sandoval & Cam, 2011). These studies suggested that students' epistemologies are complex, and multiple data sources should be used to probe students' PEs (Driver et al., 1996; Leach et al., 2000; Sandoval, 2005; 2009).

Researchers who studied epistemology as social practice asserted that characterizing students' epistemology requires paying attention to both students' PEs and the way in which the context interact with individuals. Some researchers argue that social and cultural contexts influence individuals' ways of thinking and acting (e.g., Kelly et al., 2012; Sandoval, 2005; 2009). In this view, knowledge and issues regarding knowledge are socially constructed (Kelly, 2008). Therefore, rather than paying more attention to the individual consciousness, examining epistemology should focus on the inter-subjectivity processes of a community (Kelly et al., 2012). This implies that epistemic actions of community practice depends on the individual's mind and the reflection of the other members of the community.

A call for more naturalistic studies of PE has been made by several scholars (Sandoval, 2005; 2009; Elby & Hammer, 2001; 2010; Yang & Tsai, 2012). There is evidence, for example, that what students report in a survey or an interview about science is different from what the students do in science learning activities (Leach, 2006; Kelly, 2008; Wickman, 2004). Taking into consideration both social and psychological perspectives on students' practices of science will shed light on our comprehension of students' PEs in classroom settings.

Research Questions:
1) What are the characteristics of students' physics-related PEs in scientific practices?
2) In what ways are students' PEs mobilized in school science practices? (a) In a teacher directed classroom (lecturing)? (b)In laboratory activities?

Design and Participants

In this study, we utilized an instrumental single case study with qualitative methods. Merriam (2009) defines a case study as "an intensive, holistic description and analysis of a single entity, phenomenon, or social unit" (p. 46). This study was conducted at a charter school in South US in Fall 2013. The teacher, Mr. Bryan (pseudonym), has four years teaching experiences. Nine eleventh grade students (16-18 years, 3 girls) participated. During six weeks data collection, the topics covered in this physics class included a force and motion laws unit (15 hours), and work-energy theorem (10 hours). Instructional activities included Mr. Bryan's presentation of topics and whole class problem-solving activities (15 hours). Laboratory activities included *pendulum bob experiment, motion without friction using motion detectors, motion with friction with the spring, the conservation of energy experiment,* and *gravitational acceleration* (10 hours).

METHODS

Data Collection and Analysis

In this study, we used multiple data collection methods including interviews, audio-recording of inquiry activities, field notes, and students' lab reports. All class sessions were audio-recorded and transcribed. Also, post-activity group interviews at the end of inquiry activities were conducted.

One of the researchers observed the classroom activities in person over six weeks. He conducted interviews with the nine students to have an initial idea about their understanding of the nature of scientific knowledge. Interviews were conducted by using a semi-structured interview protocol. Interview questions were based on research on dimensions of PE and the nature of science (Hammer, 1994; Tsai, 1998; Kittleson, 2011; Hofer & Pintrich, 2002). The interviews included the following prompt questions: Do you think that scientific knowledge about [physics subject that being covered] in textbooks (teachers and scientists) is always true? How do you know this equation or etc.? [showing a formula from the textbook)] If you had to teach this equation to someone, how would you do that?

Also, the researcher conducted post-activity group interviews at the end of inquiry activities. During the inquiry activity, students might not verbally speak any dimension of PE, and this would lead to some part of the PEs being left out. Therefore, the purpose of the post-activity interview was to enter into students' perspectives about the activity (Patton, 1990). The post-activity interviews included, for example, the following prompt questions: Do you think that there is anything that you find for sure in your activity? What do you do when your results do not match the expected results from the theory? How do you draw conclusions from the experiment? Interviews were audio-recorded and transcribed.

Audio-recording of students' practices of science was another primary data source. It was used to capture students' conversations during the activity. A voice-recorder device was placed on each desk (a total of four voice-recorders) where students' voices were clear and distinguishable. All lessons (a total of 25 class sessions) were audio-recorded and transcribed. Also, artifacts constructed by students were suggested as important to characterize students' PEs (Sandoval, 2009). Students' lab reports or any artifacts they constructed at the end of the activity were collected.

We utilized Cobb et al. (2001)'s "interpretive framework" to analyze data from both social and psychological perspectives. According to Cobb et al. (2001), practices can be seen as cultural practices that are "emergent phenomenon rather than an already-established- ways of reasoning and communicating" (p.121). The interpretive framework consists of two dimensions: (a) social perspective and (b) psychological perspective. Social perspective, inspired by socio-cultural theory (e.g., Lave, 1998; Rogoff, 1997) refers to "ways of acting, reasoning, and arguing that are normative in the entire classroom community" (p. 118). Psychological perspective, inspired by constructivism and theories of intelligence (Pea, 1992) is "the nature of individual students' reasoning or, in other words, his or her particular ways of participating in those communal activities" (p.119). In this analytical framework, the social and the psychological perspectives are dependent on one another. Thus one cannot exist without the other, and vice versa, so that each forms the background for the other.

The analysis of the psychological perspective is to view the teacher and students as a group of individuals who engage in acts as they interpret and respond to each other's actions (Dohn, 2011). In the social perspective we viewed the teacher and students as members of a local community who jointly establish communal practices (Kelly, 2008).

We employed the constant-comparative method. First, we transcribed all audio-recordings of class sessions and parsed each transcript into an episode (Cobb et al., 2001). Next, we summarized each episode by writing notes about the nature of activity and topic. Then, we identified themes to characterize the topic. We employed open and axial coding followed by the selective coding (Strauss & Corbin, 1990).

FINDINGS AND CONCLUSION

Thick description brings a rich description of students' PEs to the reader (Creswell, 2007). Three themes emerged: a) *can we study physics without experiment*, b) *accuracy and precision of scientific data*, and c) *practicing formula*.

Can We Study Physics without Doing Experiments: A class session Mr. Bryan and the students talked about theoretical physics (Einstein's theory) versus experimental physics (Galileo's theory) in gravity topic occurred. All students were interviewed after the class session to further understand (a) what they thought about theoretical and experimental physics, and (b) what methodology was convincing to them.

Although two students defined scientific theories as an idea needed to be tested at the initial interview, they chose Einstein's theoretical explanation over Galileo's experimental explanation. This result suggests that how students evaluated specific scientific theories is different from how they defined scientific theories in general at the interviews.
Student 1: *I guess Einstein. Because I heard of Einstein's equations through 8 grade years, and I have always heard of it. And I heard Galileo only at the 9th grade. I heard Einstein more than others and that is why it makes more sense.*

The other seven students mentioned that Galileo's experimental explanation is more convincing to them. These students defined the theoretical explanation as an idea, and mentioned that experimenting is a required way to explain phenomena in physics. The findings are consistent with the previous studies on students' ideas about scientific theory and experiment (Ibrahim et al., 2007).

Student 6: *I'd say Galileo because all other ones were what they thought, but Galileo put it in an experiment.*

Student 9: *I think experimental because if you try experimenting how gravity works, it is more likely to be better than just thinking about. Actually doing it is better.*

Accuracy and Precision of Scientific Data: In scientific inquiry students are expected to collect sufficient data and state conclusions that are consistent with their data and the theory. From an epistemological perspective, these expectations underscore how students know if scientific data are accurate and/or precise in scientific inquiry.

The following themes emerged: *scientific data must be accurate but can be precise, accuracy via following the right procedure,* and *accuracy via what the others find*.

Scientific data must be accurate but can be precise: Students are aware of the importance of the precision and the accuracy of scientific data. Students indicated that they might have concern if they did not get the same or close results while they did multiple trials.

Accuracy via following the right procedure: Students believed that their results were accurate if they followed the right procedure and established the right experiment design. Students in this class mentioned that they might have different numbers as scientific data but their interpretation would have to be the same. Students defined project-based investigations as having multiple answers. They mentioned that if an investigation had multiple answers, they did not think that they would get the same answer, suggesting that students are able to differentiate the experiments they do in terms of whether the experiment is simple or complex.

Interviewer: *Do you think your friend should reach the same results that you have found in your experiment?*
Student 8: *If the procedure tells you to do it in a certain way, then it is supposed to be the same results. If the experiment is to drop the pencil off the table, then the result should include the same results. But it is different if it is ending up floor or chair or something. It is important for them to have the same conclusion for you did right or wrong.*

Accuracy via what the others find: Students believed that their friends in the class should reach the same results. Students indicated that if they did the experiment, the other groups should have gotten the same answer with them because the experiment they did mostly have a single answer and they all followed the same exact procedure with their peers.

Interviewer: *Do you think your friend should reach the same results that you have found in your experiment?*
Student 3: *When we do lab experiments, we all get the same results. Sometimes like project, we don't always get the same results. If we drop something, we get 10 second but other groups get 11 second or sometimes we round the number. It is not always we get the exact the same results. Sometimes they have experiments like equation something like that. Sometimes there is only one right answer problem or experiments.*

Practicing Formula: One theme emerged from the students' school science practice in the teacher- directed lectures and in the laboratory activities is practicing formula.

Practicing formula in teacher-directed lectures: Typically, in problem solving activity in this class Mr. Bryan and the students worked together on the physics problems. Mr. Bryan began reading the questions to the students. After the introduction of the question, Mr. Bryan explained the necessary steps to solve the problem. Mr. Bryan's and students' talks in the following excerpts are typical conversations that occurred between him and students in problem solving activities.

Conversation of Energy- 15 Dec 2013

Mr. Bryan: *If we actually knew the mass of the rock, we could compare the mass we got and the mass they say we got. Do you expect our mass will be higher or lower than the reported mass?*
Student 2: *Higher*
Mr. Bryan: *Do you expect to get a higher mass?*
Student 2: *What was wrong?*
Mr. Bryan: *Yeah. The answer we got is 18.99. Do you think the answer that came out would be bigger than the actual reported value?*

Practicing formula in laboratory activities: Mr. Bryan's strategy for using laboratory activities was to emphasize that students should be able to collect data to do the calculations for the formula that was being covered. Sometimes, Mr. Bryan informed the students what results they would get from the experiment at the beginning of the activities. This may explain why students in the class believe that they would get accurate scientific data from an experiment if they followed the right procedure. This study provides evidence of how experiments that

were used for refuting scientific theories in physics conceal the epistemological aspects of scientific practice. It also supports the notion that in physics classes traditional teaching strategies that were centered on acquisition of certain and absolute knowledge ignore the process of knowledge production.
Interviewer: *In your class, you do a problem solving activity. Could you tell me how this activity is similar or different from the experiment that you do?*
***Student 8**: Problem solving is like what you know and how you basically bring them in paper and show in a piece of paper. Experiment is hands-on, how you show what you know. Together they both were solving the same thing but you get a feeling of hands-on during the experiment. So I think they are the same but in different ways.*

Conclusion: Although the focus of this study was not to classify students' views as naïve or sophisticated, the findings of this study show that the students in this study hold naïve beliefs about the nature of scientific knowledge and knowing. The students viewed a scientific theory as an idea or a thought that needed to be tested. The findings of this study are consistent with the previous studies on students' ideas about the relationship between scientific theory and scientific experiment. Ibrahim et al. (2007) found that, typically, undergraduate physics students viewed the experimental results as more accurate than the theoretical results, and the scientific experiments were required to provide evidence about the phenomena in physics.

One interesting finding from this study is that although Student 1 and Student 7 defined scientific theories as an idea or a thought that needed to be tested, they chose Einstein's theoretical explanation as more convincing than Galileo's experimental explanation. Yet, it should be noted that the reason behind their choice is not whether the explanation is theoretical or experimental. This is notable because this result suggests that how students evaluated specific scientific theories is different from how they defined scientific theories in general at the interviews. This result supports our argument at the beginning of the study as to why interviews may be insufficient to map students' PEs (Leach, 2000).

The students viewed the school science experiment they did as a simple experiment whether it had right or wrong answer. Therefore, they reported that the number in the lab report would be different, but the conclusion would be the same. One interesting finding from this study is that students defined project-based investigations as having multiple answers. They mentioned that if an investigation had multiple answers, they did not think that they would get the same answer. This result suggests that students are able to differentiate the experiments they do in terms of whether the experiment is simple or complex.

Sin (2014) argues that in physics classes traditional teaching strategies that were centered on acquisition of certain and absolute knowledge ignore the process of knowledge production. Furthermore, these strategies fail to have students aware of key sociological aspects of the discipline and the ensuing epistemological implications related to how knowledge claims have come into being and achieved validation (Sin, 2014). The results of this study support the previous studies' results that discuss the problems associated with traditional laboratory activities in high school classroom (Brown et al. 1989; Samaranpungavan et al., 2006; Tobin & Gallagher, 1987). The previous studies documented that typically students described their laboratory activities as simple and highly structured. Students reported that "exactly what needed to be done in the activities was given" to them. Students already knew the outcome of the experiments before they begin conducting it. In addition, the teacher observed in this study provided hints to his students that the teacher thought would help them "correctly" do the calculations.

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