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ARTICLE

High School Physics Students' Personal Epistemologies and School Science Practice

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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 audio-taped over 6 weeks. The students were also interviewed to find out their ideas on the nature of scientific knowledge after each activity. Analysis of transcripts yielded several epistemological resources that students activated in their school science practice. The findings show that there is inconsistency between students' definitions of scientific theories and their epistemological judgments. Analysis revealed that students used several epistemological resources to decide on the accuracy of their data including *accuracy* via *following the right procedure* and *accuracy* via *what the others find*. Traditional, formulation-based, physics instruction might have led students to activate naive epistemological resources that prevent them to participate in the practice of science in ways that are more meaningful. Implications for future studies are presented.

1 Introduction

Epistemology is the branch of philosophy concerned with the study of knowledge (Kvanvig 2014; Matthews 1993). Two central questions of epistemology refer to the facets of the nature of knowledge and its production: (a) how we know what we know, and (b) why we believe it (Sandoval 2005). Constructing its meaning from epistemology, personal epistemology is defined as what individuals believe about what counts as knowledge, how individuals come to know, and how knowledge is constructed and evaluated (Hofer 2008; Kelly 2016). Personal epistemology influences how students make meaning, solve problems, and learn strategies (Hammer 1994; Hofer 2008; Sandoval 2005). Recent science education documents have

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highlighted that students should develop some basic understanding of scientific knowledge (National Research Council 2007). An understanding of how scientific knowledge is generated would provide powerful tools to the citizens of democratic societies for thinking, reasoning, and decision-making in everyday life (Sandoval 2005). Duschl (2008) showed how science studies could inform science learning by noting that scientific actions include building theories and models, constructing arguments, and engaging in the social languages of special communities.

Some researchers have argued that students' personal epistemologies are tacit, complex, and require an intensive focus (e.g., Kelly 2008, 2016; Sandoval 2005). Cultural, curricular, and social contexts are considered as important elements interweaving students' personal epistemologies (Sandoval 2009; Kelly et al. 2012). To shed light on the complexity of students' personal epistemologies, some researchers have suggested examining students' school science practices (Elby and Hammer 2010; Sandoval 2005, 2009). Examining students' personal epistemologies in their practices will help us understand how students resolve competing knowledge claims, evaluate new information, make fundamental decisions, and decide on the characteristics of the data that they think are worth examining (Hofer 2001).

The main purpose of this study is to examine high school students' personal epistemologies in their practices of school science physics. Particular focus was given on students' ideas on physics concepts for two reasons: (a) among the science disciplines, students tend to view learning physics as knowledge transmission and accumulations of facts (Sin 2014; Topçu 2013), and (b) few studies have examined students' practices of physics in science classrooms (Duit et al. 2014). Students' practices in school science may reflect their tacit beliefs about the nature of scientific knowledge, the methods by which scientific knowledge is generated, and how they evaluate the evidence, data, and claims (Metz 2011; Sandoval 2009). However, few studies have examined students' personal epistemologies through students' school science practices (Metz 2011; Yang and Tsai 2012). How the ideas about the nature of scientific knowledge are interpreted in the social and cultural contexts in schools are critical. It is questionable whether the curricular context in schools positively supports students' ideas about the nature of scientific knowledge. Furthermore, it is important to understand students' personal epistemologies in practices of science because students learn from their practices (Sandoval 2005). Therefore, a need emerges to explore students' physics-related personal epistemologies in their practices of school science. Investigating students' personal epistemologies in school science practices will help us draw a better picture of the students' ideas about physics concepts.

2 Personal Epistemology

2.1 What Personal Epistemology Is

In recent years, educational psychologists have studied an individual's ideas on epistemic matters including the ways in which knowledge claims are developed and justified. In science education, studies on personal epistemology have built on these psychological assumptions to explore students' understandings of scientific knowledge construction (Berland and Crucet 2016). Researchers, however, have used various terms for personal epistemology including the nature of science (e.g., Smith et al. 2000), epistemic cognition

(Bråten et al. 2013), epistemological beliefs (e.g., Kittleson 2011), and epistemological resources (Elby and Hammer 2010).

Personal epistemology refers to an individual's ideas about knowledge and knowing. Research into personal epistemology began with Perry's (1970) longitudinal qualitative work on Harvard undergraduate students. Although various stages for the development of personal epistemology were put forward, common views are that novice individuals tend to see knowledge as static and an accumulation of separate facts and if change occurs—it has to be a move from naïve views through more sophisticated views.

However, Hammer and Elby (2002) argued that there have been problems with the existing ontologies regarding personal epistemology. Hammer and Elby viewed the ontology as "holding a presumption of unitarity" (p. 187). They asserted that not everyone who answers the same question with the same way or exhibits the same tendency to a specific event can be said to have the same thought processes or beliefs. Therefore, they offered a new ontology, referring to epistemic resources, rather than beliefs. They also proposed a list of epistemic resources as possibilities (e.g., knowledge as propagated stuff) and suggest that much more needs to be explored.

Elby and Hammer (2010) were not interested in epistemic development. Rather, they were concerned with how epistemic resources can be productive in a particular context (e.g., during a lab activity). They suggested that "a belief can be productive if it generates behavior, attitudes, and habits that lead to 'progress' as defined by the given person or community" (p. 555). Further, they questioned the consensus view of sophisticated personal epistemology reflected in the surveys, interviews, and other methods to map students' personal epistemologies. Their argument consisted of two ideas: (a) scientific knowledge is "tentative," and (b) scientific knowledge is "constructed" by humans. First, they argued that even though all scientific knowledge is constructed by humans, in some contexts, it is possible for scientists and students to view scientific knowledge as discovered in nature. They asserted that it is possible for some students to believe that scientific knowledge is about discovering the objective truth in the universe, for example "the Earth is round." Second, epistemic sophistication in most personal epistemology surveys is viewed as believing a particular generalization such as that scientific knowledge is tentative. Elby and Hammer argued that the view that "scientific knowledge is tentative" does not apply equally to all scientific knowledge. For example, those people who believe that "the earth is round and it is not flat" and that "this scientific knowledge will not change in the future" does not mean that they have naïve personal epistemologies. The scientific knowledge that is being discussed always has some contextual dependencies that shape people's responses about the nature of scientific knowledge or their personal epistemologies. Elby and Hammer suggested that one to one conversations have a better chance of uncovering the contextual dependencies. Because of the strong consensus on sophisticated personal epistemologies, researchers often neglect the context they are working.

Elby and Hammer (2010) used the idea of *epistemological frame* to describe the context and the resources that an individual or a group of individuals activate, related to knowledge. In other words, an epistemological frame is a locally coherent activation of a network of resources (Elby 2009; Elby and Hammer 2010). The observable units of a student's personal epistemology generally include not a single resource but a locally coherent activation of a network of resources. Elby and Hammer asserted that some epistemic resources are activated by a person over and over, and became a strong network of resources that may look like a stable belief or theory.

2.2 Personal Epistemology and School Science Practices

A growing body of research has focused on high school students' personal epistemologies in science. Research has reported that most students at the high school level tend to be not sure whether scientific knowledge is absolute (Alpaslan et al. 2016; Kılıç et al. 2005). Students believe that scientific knowledge can be wrong or right and that only experts can tell the correctness of information (Yang 2005). Wu and Tsai (2011) found that students might not be able to apply their relevant knowledge in their decision-making on socio-scientific issues (SSIs) and tend to make intuitive decisions instead. Similarly, students might not be able to recognize the importance of evidence in the evaluation of theories (Thoermer and Sodian 2002).

Some studies have reported that although students' inquiry activities are similar to the ways in which scientists study the world, students' views towards scientific knowledge is unchanged and they tend to hold a naïve personal epistemology (Khishfe and Lederman 2007; Sandoval 2005). For example, Sandoval and Morrison (2003) examined eight high school students' ideas about the NOS during a biology inquiry unit. They found that after a 4-week inquiry unit, students still believed that the purpose of science was to search for the right answers about the world. In another study, Moss (2001) found that after the 11- and 12-grade students participated in general science project-based learning activities during an academic year, most of their epistemic views remained unchanged.

The ineffectiveness of these research attempts might be due to the assumption that learning about the nature of science occurs naturally through "doing science" and engaging in inquiry activities (Berland and Crucet 2016). To address this issue, some researchers have argued that we should change our theoretical and methodological perspectives regarding personal epistemology, and have suggested that studies should focus on how the content shapes student' acts and epistemologies. Sandoval (2005), for example, distinguished between two types of personal epistemology: formal epistemology and practical epistemology. He defined formal epistemology as the beliefs that students hold about the profession or formal science, and practical epistemology as the beliefs that the students put into actions in their own practices. He also suggested that studies should focus on the practical epistemologies. Furthermore, Berland and Crulet (2016) argued that holding a more sophisticated belief on the nature of scientific knowledge as measured through students' descriptions of what counts as knowledge and how knowledge is constructed and evaluated does not indicate that students will engage in practices of scientific knowledge construction in more sophisticated ways. This implies that students' ideas about the nature of knowing and knowledge should be studied through contexts that shape their own personal epistemologies.

2.3 Personal Epistemology as Contextual Practices

Interviews and surveys are the most popular instruments to probe students' personal epistemologies 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 et al. 2006). For instance, the Nature of Science Interview (Smith and Wenk 2006) asks such questions as "what do you think the goal of science is" (p. 778). 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 and Cam 2011). For instance, Leach et al. (2000) investigated whether students' epistemic reasoning is consistent across different kinds of questions. Students were asked to respond to two written items that consisted of multiple statements addressing epistemological issues (e.g., relationships between scientific theories, empirical data, and the design of investigation). In terms of the consistency of students' reasoning across the two items, no evidence was found.

Similarly, Sandoval and Cam (2011) examined young children's epistemic judgments of the causal justification types. A set of stories asked students to compare a pair of justifications for a causal claim, choose the justification that they thought was better, and explain why. Each story comprised the base justification (authority—heard from an authoritative source like a book or magazine or plausible mechanism—a causal mechanism that explained the claim) and the evidentiary justification (presents the results of experiment data with graphs). Of 26 students, 15 chose the evidentiary justification in at least three of the four stories; seven chose the base justification in at least three of four stories; three chose the evidentiary in two stories and the base justification in the other two stories; and one chose none of the evidentiary justifications in all four stories. These results suggested that a student can have a naïve view (choosing authoritative justification) or a sophisticated view (choosing evidentiary justification) across different items. These studies indicate that students' epistemologies are complex and multiple data sources should be used to probe them (Driver et al. 1996; Leach et al. 2000; Sandoval 2009).

Characterizing students' epistemologies requires paying attention to both these and the way in which the context interact with individuals (Kelly 2008). Elby and Hammer (2001) argued that research should focus on the way in which context influences the characterization of personal epistemology. Paralleling Hammer and Elby's (2002) point, some researchers argued 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 the epistemic actions of the community depend on the individual's mind and the reflections of the other members of the community.

A few researchers have examined students' epistemologies in practices of school science (e.g., Hammer and Elby 2003; Rosenberg et al. 2006; Sandoval and Reiser 2004; Kittleson 2011). The research revealed that students' epistemic approaches are fragmented and localized in particular situations (Sandoval and Reiser 2004). For example, Rosenberg et al. (2006) studied how epistemological resources played roles in students' approaches to complete scientific inquiry activities. Analysis of students' discussions revealed that they employed various epistemic resources (e.g., knowledge as propagated stuff and knowledge as fabricated stuff) that could be characterized as coherent rather than discreet pieces in a segment. There were also shifts from one segment to another in students' sense of what constitutes knowledge. Students' discussions showed several local (depending on the context) coherences. These studies support Hammer and colleagues' argument that the stability of an individual's epistemic stance can depend on the context, social or material.

A call for more naturalistic studies of personal epistemology has been made by several scholars (Sandoval 2009; Elby and Hammer 2010; Kelly 2016; Yang and Tsai 2012). In this call, the suggestion made was to analyze the context of students' interactions and the constructed artifacts (Sandoval 2005, 2009). Knowing is an adaptive process that organizes an individual's experiential world within a social setting (Kelly et al. 2012). There is evidence, for example, that what students report in a survey or an interview about science is different from what they do in science learning activities (Leach 2006; Kelly 2008; Wickman 2004). Examining students' practices of physics will shed light on our comprehension of students' personal epistemologies in school science settings.

3 Methods

This study aims at depicting students' personal epistemologies within the practices of high school physics. The theoretical framework guiding this study has important implications for the methodological approaches. The epistemological resources framework asserts that students' personal epistemologies are tacit and students may not verbally describe epistemological resources that they employ in a particular context. In addition to this, because students' personal epistemologies are context-dependent, the epistemological ideas that the students describe through the interviews may not reflect their ideas that they put into action in their physics classroom practices. To overcome this issue, researchers who have studied epistemological resources recommend observing students and interpreting what they do and say in their practices of science in a particular context (Berland and Crucet 2016). Therefore, we analyzed a group of high school students' epistemological resources in their physics classroom practices by employing the case study of methodology with qualitative research methods.

3.1 Research Setting and Participants

In this study, we used qualitative methods to explore students' physics-related personal epistemologies in school science practices. Merriam (2009) defined a case study as "an intensive, holistic description and analysis of a single entity, phenomenon, or social unit" (p. 46). A case study should be a bounded system that the researcher can limit the number of participants or the timeline of the study (Stake 1995). In this study, the physics classroom at a charter school is considered as a unit of analysis by place in which the students participate in inquiry activities and time covering inquiry activities on two subject topics.

This study was conducted at a charter school, located in an urban area at the South Central United States, which is defined as "publicly funded, nonsectarian school that operates under a written contract, or charter from an authorizing agency such as a local or state board" (Texas Education Agency 2006, p.312). The students at the school came from a low-socio-economic status, 55% of students who qualified for free or reduced lunch. The student population of the school was kindergarten to high school. Students at the school performed well on the state assessment program that ranked among the top 25% in the state for science at the high school level. When the study took place, 11 students at 11th grade enrolled in a physics course with one teacher. Of the 11 students, nine (3 girls and 6 boys), with ages ranging from 16 to 18 years, consented to participate in all parts of the study. Two students identified themselves as Hispanic, two as African American, and five as White.

The teacher in this study, Mr. Bryan (pseudonym), had 4 years of teaching experience and had also been working at the school for 4 years. He held a Bachelor of Physics. When the study was conducted, he was teaching the physics course (5 h), SAT Enrichment, and Pre-Calculus courses (a total of 10 h). Mr. Bryan's primary purpose was to prepare his students for the State of Texas Assessments of Academic Readiness (STAAR) exam. He wanted his students to receive high scores in the physics portion of the STAAR exam. His teaching style was traditional and he often lectured. The classroom activities he used pertained to solving standardized physics tests. We believe that exploring students' personal epistemologies in this traditional context is important because research indicates that most physics teachers in the USA implement traditional instructions in the teaching of physics (Neuschatz et al. 2008).

Over the 6 weeks of data collection, the topics covered were a force and motion laws unit without force of friction (10 h), Newton's laws of motion including force of friction (5 h), and work-energy theorem and energy transformation and conservation of energy (10 h). Of 25 h, 15 h was devoted to direct instructional activities or lecturing. Direct instructional activities mostly comprised Mr. Bryan's presentation of topics and the whole class problem-solving activities. Laboratory activities included a pendulum bob experiment, motion without friction using motion detectors, motion with friction with the spring, the conservation of energy experiment, and gravitational acceleration. A total of 10 h was devoted to laboratory activities.

The direct instructional activities and laboratory activities were implemented in the same room. During the laboratory activities, the students worked in groups of two or three. Mr. Bryan assigned students to their groups. Students worked with the same group members at their data collection activities.

3.2 Data Collection Methods

In this study, we used multiple data sources including formal and informal interviews, audio recordings of the inquiry activities, field notes, lab reports, and the collections of documents and artifacts. At the beginning of the study, formal interviews with the nine students were conducted to have baseline information about their understanding of the nature of scientific knowledge. Interviews were conducted by using a semi-structured interview protocol presented in the Appendix. We designed the interview questions based on the previous studies on personal epistemology. The interview questions addressed the dimensions of the personal epistemologies defined by Hofer and Pintrich (2002) (See Tables 1 and 2). We focused on these dimensions because other researchers who examined students' personal epistemologies in their practices of science (e.g., Kittleson 2011) also framed students' personal epistemologies according to these dimensions. In addition to this, Hammer and Elby (2002) grouped epistemological resources according to these four dimensions. 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? What is a theory? After scientists have (had) developed a theory, does the theory ever change? What kind of change may occur in the development of science? How and why? Do you think your friend should reach the same results that you found in your experiment? (scientists, too). 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?

Because the school policy did not allow the students to be video-recorded, we audio-recorded the students' conversations. Language is key to capturing students' ideas about the nature of scientific knowledge (Kelly and Crawford 1997; Lemke 1990). Thus, a voice-recorder device was placed on each desk (a total of four voice-recorders) so that students' voices could be recorded in a clear and distinguishable manner. All lessons (a total of 25 class sessions) were audio-recorded and transcribed. The artifacts constructed by the students in the class activities were suggested as important in order to characterize students' personal epistemologies (Sandoval 2009). We collected our students' lab reports or any artifacts they constructed at the end of each activity.

Table 1 Definitions of the dimensions of personal epistemology

The dimensions of personal epistemology	The definition of the dimensions	Sample interview questions
Certainty of knowledge	The perceived stability and the tentative knowledge	Do you think that scientific knowledge about …. (physics subject that being covered) in textbooks (teachers and scientists) always true?
Simplicity of knowledge	The relative connectedness of knowledge	What is experiment? Why do scientists do them?
Justification of knowledge	How individuals proceed to evaluate and warrant knowledge claims	What is your understanding of the word “data”?
Source of knowledge	Either that knowledge resides as an external source or is constructed by learners	How do you know this equation or etc.? (showing a formula from the textbook) If you had to teach this … to someone, how would you do that?

All interview questions were provided in the Appendix

Over 6 weeks, the classes were also observed and field notes were taken. Because the audio recordings could have missed some of the visual clues relating to students’ practices, the first author of the study acted as an observer in the classroom activities and took field notes over 6 weeks. As suggested by the participant observation tradition (Kelly and Crawford 1997), the first author used three kinds of observations, such as descriptive, focused, and selective observations. Whereas descriptive observations were to understand the social situation by asking “what is happening in the classroom,” focused observations were to understand how scientific

Table 2 Sample codes emerged from the initial interviews

Epistemological sources	Codes describing the dimensions of personal epistemology	Example from the initial interview data
Accuracy via what the others find	Getting other opinions	Interviewer: How do scientists know if they are right about something? Student 1: They do several trials. Like experiments, they also probably get other opinions or other scientists. Interviewer: What kind of opinions? Student 1: Like if they do not know something, they can go ask somebody else. Therefore, they actually know others’ answers.
	Correcting their experiment	Student 3: Because just help each other out. If one scientist wrong, and other scientists got another answer, and then they can like see what they did wrong.
	Others’ results as a way to test their results	Interviewer: Do you think your friend should reach the same results that you have found in your experiment? Student 8: Not always. because if I am wrong when doing an experiments, and I got different answer from everybody else, and everybody else has the same answer and I am only the person who got the wrong answer, then that helps me see that I did something wrong.

knowledge has been constructed in the classroom. Finally, selective observations were employed to zoom out specific actions by asking more specific questions including "How do students justify the data that they collect?" and "How do students justify the competing theories that use different methodologies?" The participant observer's daily journals and audio recordings were compiled to document the thick description of what has happened in the classroom.

During data collection, the observer's role changed from being passive to being an intermediate participant. That allowed the observer to capture the local circumstances and have the opportunity to conduct informal interviews with the students as they completed their experiments. Because Mr. Bryan's instruction was mostly traditional, interactions among the students were rare; even during the laboratory activities, students had barely talked to each other. Therefore, informal interviews were conducted after the activities to document students' perspectives about the activities (Patton 1990). Informal interviews and post-activities paved the way to explore students' ideas about the nature of scientific knowledge and knowing. Furthermore, because students might not be able to explicitly pronounce the epistemological resources that they used in a particular context, informal interviews provided us with another venue to capture what they really thought and their reasoning. For example, in one classroom activity, students and Mr. Bryan were talking about Einstein's thought experiments and Galileo's experiment on gravity. Informal interviews about their views on Einstein's, Galileo's, and Aristotle's theories of gravity enabled us to capture the epistemological resources that students used when justifying theories with different methodologies. The post-activity interviews were conducted after each class sessions. The interviews included the following prompt questions: "How do you prepare for the activity?," "How do you define the purpose of the activity?," "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?," and "How do you draw conclusions from the experiment?" The post-activity interviews were also audio-recorded and transcribed.

3.3 Data Analysis Methods

The initial formal interviews were coded to identify students' general ideas about the nature of scientific knowledge, what they think about scientific theories, what they think about the role of evidence in theory building, and how they evaluate scientific knowledge and theories. Findings from the previous studies (e.g., Driver et al. 1996) were used as the starting points for the analysis. Regarding the students' ideas about the nature of knowledge and knowing, the codes used in the analyses included *getting other opinions*, *theories are just thinking*, *experiments are to test if theory is right or wrong*, and *Mr. Bryan as the first source of knowledge*. For the purpose of attaining a coding reliability, we asked an independent coder to code 25% of all our interview transcripts. The coding agreement between the independent coder and the authors was 89%, which is a desirable coding reliability.

To explore students' personal epistemologies in their practice of physics, the analyses of the initial interview data were conjugated with the data collected by the field notes and the audio recordings. Several steps to analyze audio recordings were followed. First, all audio recordings of the class sessions were transcribed. Then, all the transcriptions were read and each transcript into an episode was parsed (Kittleson 2011). Next, we summarized each episode by taking notes about the nature of the activities and the topics. Then, the themes to characterize the topics were identified. Some episodes were not related to students' personal epistemologies. We highlighted the personal epistemologies addressed in students' practices of physics. To analyze the data sets, we employed the constant-comparative method (Glaser and Strauss 1967). All interviews were transcribed and merged with field notes and other documents. Then, open and axial coding followed by the selective coding were employed (Strauss and Corbin 1998) to analyze the transcribed verbatim, field notes, and other documents (See Table 3).

4 Results

A qualitative case study was chosen to describe how ideas about scientific knowledge are mobilized in the school science practices. Therefore, analysis, descriptions, and interpretations were used to generate thick description (Merriam 2009). Thick description brings a rich description of students' personal epistemologies to the reader (Creswell 2007). Below, the three emerged themes, (a) *can we study physics without experiments*?, (b) *accuracy and precision of scientific data*, and c) *practicing formula*, are presented.

4.1 Can We Study Physics Without Doing Experiments?

The first theme emerged from the analyses of students' initial interviews and Mr. Bryan's presentation in the classroom was "can we study physics without doing experiments?" This theme emerged from the conversations between Mr. Bryan and the students when Mr. Bryan was lecturing about the motion in an elevator and explained Einstein's thought experiment about the motion in the elevator. Below is the dialog between Mr. Bryan and the students on the theoretical physics versus experimental physics in gravity was quoted:

Newton's Law unit: 20-Nov-13

Student 2: What would happen if the elevator goes down?

Mr. Bryan: You will be weightless in the elevator. What if Einstein says that you are in a big manned shuttle at free fall in the elevator? So, you'd think that you were in the space because you were weightless. In the contrast, if you were in the elevator in the space and swinging around but this time you'd not think you were in the space because you'd have artificial gravity that keeps you on the floor. That is where his thought experiment is turning around his relativity theory.
Student 5: Didn't he do any experiment like Aristotle?

Table 3 Sample codes for "can we study physics without experiments" emerged from students' practice of physics and post-interviews

Epistemological sources	Codes describing the epistemological sources	Example from students' practice of physics and post-interviews
Scientific explanations are more believable with experimenting	Experimenting is more credible	Einstein has not been proven right to wrong because he did not try to do experiment, to find what is actually true
	Experiment tests to see it if it is correct	Aristotle said something about everything without testing
	Theory is just thinking	Thinking can be a theory but it has to be something real scientific
Scientific explanation are more believable with technology	Technology can prove scientific theories	So better technology proved this theory
	Recent scientific theories are more convincing	Because it is more recent than others that they can use technology
Scientific explanations are more believable with social acceptance	Recognizing the theory make it more convincing	I heard Einstein more than others; thus he makes more sense

> Mr. Bryan: Did he just think like Aristotle or did experiment like Galileo? No. He did some experiments himself but he was more of a theoretical physicist; he had other people do his experiments during his life time and after his death.
>
> Student 8: Can we just do physics without experiment?
>
> Mr. Bryan: You can be a theoretical physicist. So actually, Aristotle's theoretical explanation and Galileo's experimental ball theory are still around today. You can be a theoretical physicist, or you can be an experimental physicist. They both work. Theoretical physicists understand the value of experimentation but it takes time for someone to figure out how to set up the experiment. For example, again Einstein's theory: he thought that light is affected by the gravity. His theory is that gravity should affect light. Well, so there is a solar eclipse coming from the sun. A bunch of guys experimented during the solar eclipse, so that they were able to have a good look at the stars that behind the sun. You usually cannot see these stars because there is dimmed light, like a flash light. But when the sun was blocked they can see those stars and they were able to see where they actually are versus where we thought they were. The results came out that "Yes the light was bent a little bit, making the star located at a wrong spot." This experiment proved that while stars' lights pass the sun, the sun's gravity bent the stars' light. That showed us that Einstein was right.

Mr. Bryan used Einstein's thought experiment to have students visualize the effect of gravity in an elevator. The discussion then turned to students' questions about theoretical versus experimental physics. Students seemed to view experimentation as the only way to investigate phenomena in physics. Mr. Bryan used Einstein's theoretical explanation and the substantial experiments on the effect of gravity on light to emphasize how theoretical physics can lead experimental research about gravity in physics and how these approaches can work together. By emphasizing that there are other ways to investigate the phenomena in physics rather than experimentation, Mr. Bryan reinforced the idea that scientific methods are diverse.

A worthwhile point was that students articulated their idea that the only way to study physics was doing experiment, and they did not think of theoretical physics as a way to answer questions about physical phenomena. To get a better sense about students' ideas on theoretical and experimental physics, nine 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. This interview provided an insight into students' ideas of how they evaluated scientific theories, the evidence that supports them, and the sources of scientific knowledge. In the post-interview, we asked students about their opinions on theoretical physics (Einstein's and Aristotle's theories) versus experimental physics (Galileo's theory) and which one they considered as more convincing.

Our analyses of the post-interviews with the students generated three epistemological resources that the student employed to justify their reasoning in this particular context: *scientific explanations are more believable with experimenting, scientific explanations are more believable with technology,* and *scientific explanations are more believable with social acceptance*. The student's preferred choice of scientific methods about investigating the gravity revealed that overall students were more likely to choose the experimental methods. Accepting theories that depended on experimental data and reasoning showed that students employed the epistemological resource that *scientific explanations are more believable with experimenting*. As mentioned earlier, this epistemological resource emerged from students' conversations with Mr. Bryan and the initial interviews. Given previous research on high school students (e.g., Driver et al. 1996), it is not surprising that the students indicated experimentation as explaining the phenomenon of gravity and that they tended to employ such epistemological resources:

Student 2: I guess it is experimental one because if it is tested and then we can see if it is true or not. Like Aristotle, he thought that one heavier mass falls faster but that one was not true. Moreover, Galileo is the one who did the experiment to prove that Aristotle was wrong. Einstein was the theoretical person. Moreover, he will not be always correct because he needs to test it. He has not been proven right to wrong because he did not try to do experiment, to find what is actually true.
Student 6: I would say Galileo because all other ones were what they thought, but Galileo put it in an experiment.

Two of the nine students in the class chose Einstein's theoretical explanation as more convincing. When we looked at students' explanations of their choices, their reasoning differed. Student 1 who chose Einstein's theoretical explanation about gravity explained his reasoning as the following:

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 and Aristotle only at the 9^{th} grade. I heard Einstein more than others and that is why it makes more sense.

Student 1 indicated that Einstein's theoretical explanation on gravity is more convincing to him because he had heard more about Einstein. Rather than whether the explanation is theoretical or experimental, interestingly his choice was based on who put the explanation forward. Another interesting point on his explanation is that he chose Einstein because Einstein's theoretical explanation is widely accepted. His explanation indicates that he believed that a scientific explanation is more likely to be true if it is widely accepted by the others. This indicates that he employed the epistemological resource that *scientific explanations are more believable with social acceptance.*

Student 7 who chose Einstein's theoretical explanation about gravity explained his reasoning as the following:

Student 7: I guess Einstein because it is more recent that they can use technology than others. Technology makes more people interested in how stuffs work. People have more resources to help them figure out how things work. They have more reliable resources.

Student 7 indicated that Einstein's theoretical explanation on gravity is more convincing because it was more recent than others. Like student 1, the reason of his choice was not whether the explanation was theoretical or experimental. Rather, he interestingly indicated that a recent theory is more convincing. His explanation for his reasoning can be interpreted in two ways. First, he believed that technology makes the scientific theories more reliable. Second, he viewed the development of scientific theories as cumulative. His explanation indicates that he believed that scientists use a combination of firsthand and secondhand sources of information to develop theories. That gives a clue that student 7 used the epistemological resource that *scientific explanations are more believable with technology.*

Overall, these students' explanations suggest that they did not realize that scientists use different methods to answer their research questions and that they use sophisticated epistemological resources. In addition, triangulations revealed that the students' answers to the initial interview questions were inconsistent with their answer to the post-interview questions, which were more specific and fine-grained. At the initial interviews, all students defined scientific theories as just ideas that were required to be tested. However, two students chose the theoretical explanations over the experimental ones. This inconsistency can be explained by the context that influences the epistemological resources that students use.

4.2 Accuracy and Precision of Scientific Data

Among the other steps outlined by NRC (2007), scientific inquiry includes observing, measuring, being concerned with accuracy, precision, and measurement error of scientific data. In scientific inquiry, students are expected to collect sufficient data and state conclusions that are consistent with both their data and the theory. From an epistemological perspective, these expectations underscore the importance of dealing with what counts as scientific data and how students know if scientific data are accurate and/or precise in scientific inquiry.

Accuracy of scientific data refers to how close the data are to the accepted values. In other words, accuracy of data means how close the data collected from an experiment are to the expected results that were obtained or calculated from the theory. The precision of scientific data refers to how close the data points obtained from different trials in the same setting are to each other. Collecting both accurate and precise data are main concerns of scientists.

Analysis of the field notes and students' speech revealed that students use different epistemological resources on evaluating scientific data in terms of accuracy and/or precision. Two epistemological resources emerged from triangulation of all data sets: (a) *accuracy* via *following the right procedure,* and (b) *accuracy* via *what the others find*.

4.2.1 Accuracy Via Following the Right Procedure

One of the epistemological resources that emerged from students' practices is that they believed that their results were accurate if they followed the right procedure and established the right experiment design. To illustrate students' ideas about the accuracy of scientific data via the right experiment design, we present an excerpt from a conversation during an inquiry task. In the below excerpt, the students articulated what they thought about collecting accurate scientific data. In the excerpt, group 2 members were working on the pendulum bob experiment in which students calculated the amount of the kinetic energy converted to the potential energy by measuring the height that the block went up so that they could find the velocity of the block at the beginning:

Work-Energy Theorem unit: 12-December, 13

Student 2: This is not scientific

Mr. Bryan: Why do you think it is not scientific?

Student 2: Because what I am measuring does not seem right. I measure the height but it does not seem that I am measuring it correctly. (The student pointed out that while she was measuring the vertical distance that the block moved, she referenced the edge of block). The height is different for each point on the block.

Mr. Bryan: What is your solution?

Student 2: I don't know. Maybe we should get some point average.

Mr. Bryan: No. Think.

Student 4: If we measure the distance from the center of the block, I think that we will not make a mistake.

Mr. Bryan: Yes. Get your reference point from the center of the block.

In this excerpt, the students did not define what they were doing as scientific because they thought that they were doing a systematic error that violated the accuracy of the scientific experiment. After they talked with Mr. Bryan about the possible solution, the students decided to measure the height that the block went up from the center of the block. This indicates that collecting data in a correct way was considered as collecting accurate scientific data. In another instance, Mr. Bryan reminded the students about the importance of following the right procedure for a scientific experiment:

Force and Laws of Motion unit, 21 Nov-13

Mr. Bryan: You should keep the records of your trials if it is the same with other trials. If you start off wrong, you will continue wrong. You cannot change your conditions during the experiment. It renders all trials invalid.

Students believed that following the right procedure or correctly collecting data during the experiments would help them obtain accurate scientific data and then make a correct conclusion. Students in this class mentioned that they might have had different data but their interpretation would have to be the same. Students indicated that they might have different reference points or different materials that did not exactly match with other. Yet, they would eventually reach the same conclusion. The following excerpt illustrates students' ideas about how they would evaluate the conclusion of a scientific experiment:

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.

4.2.2 Accuracy Via What the Others Find

Another epistemological resource that emerged from the students' school science practices on the accuracy of scientific data was that students in this class believed that their friends in the class should have reached the same results. Students indicated that finding the same results from an experiment depended on what they were doing in the experiment. Students indicated that if they did the same experiment, the other groups should have arrived at the same answer with them because the experiment they did mostly have one single answer and they all followed the same exact procedure with their peers. If the experiment had multiple answers, they might have not arrived at the same result. The following excerpt illustrates how the students evaluated the accuracy of their data through their friends' findings:

Force and Laws of Motion unit, 22 Nov 13

Student 5: What you got g for 50 inches?

Student 4: 374.2 we got at the first.

Student 5: Yeah it is close. I think we are doing right.

In the excerpt presented above, group 4 members were not sure about their gravitational acceleration measure in inches. Since they did not know the value of the gravitational acceleration in inches, they asked group 2 member what they had found to figure out if they were on the right track. Group 2 members told them a value that was close to theirs (g = 374.2). Group 4 members compared the two values. One noteworthy aspect of the excerpt presented above is that students took for granted that their friends would have arrived at results similar to their own since they were doing the same experiment and following the same procedure. The epistemological resource that *accuracy* via *what the others find* was found on the pre-interviews and the post-interviews:

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.
Interviewer: What do you do if you have had different results from your friends? (post-interview)

Student 1: If I am doing an experiment, and I got different answer from everybody else, and everybody else has the same answer. As I am only the person who got the wrong answer, then that helps me see that I did something wrong.

Students indicated that they used their friends' findings from the same experiment to see if their results were accurate. One interesting point that student 3 mentioned here is that when he worked on a project-based, open-ended experiment with multiple answers, he was less likely to use his friends' findings. The following excerpt illustrates how students viewed experiments that might have multiple answers:

Interviewer: Do you think a scientist should reach the same results that the other scientists have found?

Student 8: Probably experiments they do have multiple answers. Therefore, they will not get the same answers. It depends on the experiments they are doing.
Interviewer: Do you think a scientist should reach the same results that the other scientists have found?

Student 7: Possible. I do not know any scientist. It may be little bit different. They do experiment on some hard projects. They can get different results I guess. It just depends on how they are doing experiment. For example the gravity thing, Galileo, and others. They all believed in different things, and it was actually the same thing but they had different ideas about it.

To sum up, students employed different epistemological resources to assess the accuracy of scientific data. Previous research has reported that students tend to believe that if they follow the given procedure correctly and without any mistake, their data will be correct and they will make the correct interpretations (Chinn and Malhotra 2002). In this study, we explored that students use an epistemological resource, that is, they adjust their findings and then their interpretations according to what their peers have found. In addition, some students in this class reported that the differences between their experimentation and the scientists' experimentation depended on the characteristics of the scientific question that led to the experiment. If the experiment had a single answer, they should find the same result. If the experiment was open-ended and it had multiple answers, they might find different results. The students distinguished their experiments from the experiments that scientists do. They defined the experiments that scientists conduct as the "hard projects" that might have multiple answers. A noteworthy aspect of students' ideas on the accuracy via what the others find is that they were able to recognize and react differently to the structured and single answer experiments and unstructured, open-ended, and multiple answer experiments in terms of the accuracy of scientific data.

4.3 Practicing Formula

Another epistemological resource emerged from the students' school science practice in the teacher-directed lectures and in the laboratory activities is practicing formula. Practicing formula is an epistemological resource that the students employed in teacher-directed and laboratory activities. Practicing formula includes the ideas that students (a) memorized the formula, (b) were given the data that they would use in teacher-directed lectures, or they collected in laboratory activities, and (c) made a mathematical calculation and come up with a right or wrong answer..

4.3.1 Practicing Formula in Teacher-Directed Lectures

During the lectures, Mr. Bryan and the students typically worked together on the physics problems. The problems that would be covered were presented to students on the whiteboard via a computer projector. Mr. Bryan read the questions to students. After the introduction of the questions, Mr. Bryan explained the necessary steps to solve the problem. When it was necessary, he asked the students some questions to make them aware of their own approach to solve the questions. The conversations in the lectures occurred sometimes between Mr. Bryan and one single student and sometimes between Mr. Bryan and several students. Mr. Bryan's and the students' dialog in the following excerpts illustrate some typical conversations:

Conservation 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 that the answer that came out would be bigger than the actual reported value?
Student 8: No

Mr. Bryan: If we ended up a mass too small, what would that be?

Student 6: Mass.... (Inaudible)

Mr. Bryan: We are assuming a perfect conversion from the work to kinetic energy, right?

Students: Right

Mr. Bryan: Which is assuming no friction loss. This one has to assume completely the friction on the surface. If we have friction, where should some work go?
Student 1: Toward friction

Mr. Bryan: Yes. It is towards friction, which actually means that there is less kinetic energy work from what we got. That gives us a smaller mass. So we expected the reported value different from what we calculated.
Force and Motion unit- 11 Nov 2013

Mr. Bryan: Let's start with good questions. What did we call the force the table exerting to the box?

Student 1: Normal.

Mr. Bryan: Right. It is the normal force. What is the normal force again?

Student 9: It is the counter force.

Mr. Bryan: Not exactly. It is the counter force of gravity, right. It is the counter weight of the box. This is saying that it equals to 40 N.
Student 9: It is 40 N because the bigger box is heavier than the smaller box.

Mr. Bryan: Does anyone agree with Student 9 that it is 40 N?

Student 7: Yes.

Mr. Bryan: Why?

Student 7: It looks like it is going to stay there.

Student 5: It is going to stay there.

Student 3: If it is 40, then it will need more weight to take it off from the table.

Mr. Bryan: Wrong. They are not asking how much force the table pushing up the box.

Student 6: Then it is 70.

Mr. Bryan: Right, it is 70 if it is resting there.

Mr. Bryan: Let's draw the force diagram together. I got the force of the gravity. It is going to pull down, right. What is going to try to hold it up?
Student 1: The rope.

Mr. Bryan: Yes. It is the rope. What do we call it?

Student 2: Tension

Mr. Bryan: Yes. Are these equal?

Students: Yes.

Mr. Bryan: How do you know? There is no movement, right? They are equal. The fact, there is no acceleration. So I am pulling this rope with 40 N. On this side, it will be 40 N, right. I got gravity down. And I got normal force up, right. I know that the tension close to the normal has to equal the weight of the box.
Student 9: So, the force for the tension is 30 N.

Mr. Bryan: Yes. The force for the tension is 30 N.

In the first excerpt, Mr. Bryan introduced a problem on the conservation of energy. He asked the students what they would expect if the mass of the rock they got was higher or smaller than the reported mass of the rock. After he replied that student 2 gave the wrong answer, Mr. Bryan re-worded the question. Next, he explained the reason of finding a smaller mass. Finally, the students understood that Mr. Bryan wanted to tell them in the question that some of the energy would be wasted because of the friction on the surface. In the second excerpt, Mr. Bryan and the students were working on a force and motion problem. In this problem, Mr. Bryan wanted to show to the students how to calculate the normal force and the tension force on the rope.

4.3.2 Practicing Formula in Laboratory Activities

Another instance of practicing formula occurred in laboratory activities. In a typical laboratory activity, the students were asked to collect data as to calculate another variable in the formula. The following excerpt illustrates Mr. Bryan's instructions to students before they started experimenting:

Force of Friction – 18 Dec 2013

Mr. Bryan: Today we will investigate the friction. Every station has one of these blocks. If you look at the bottom of your block, you see different materials that are glued on the bottom of the block. Some of you got felt, some of you got a smooth plastic, and some of you have a metal. And you have a force sensor. It has got a hook on it. Here is what you are going to do. I have masses in that box over there. What you are going to do is to put some mass, I don't care how much, but you should know how much you are using. So put some mass on the cart. There is a little hook there. You hook with the hook. And you are going to able to record how much force you are pulling on this with. Put it down on the table. I want you to pull gentle and slowly because what you are measuring is how much force does it take to get it to start moving. The more mass you put in it the more force you will need it for going. If you feel like if it is take off fast, put more mass on it. I do want to see some calculations because your goal is to figure out what is the μ on the surface is. We are practicing this formula again. The force of friction is how much force you will apply to get it moving. It is the data you are measuring, this is the mass you put in it, and then g as 10.

Mr. Bryan's strategy for using the laboratory activities was to emphasize that students should be able to collect data to do the calculations with the formula that was being discussed. One noteworthy aspect of the excerpt presented above is that Mr. Bryan had already informed the students what results they would get from the experiment. This may explain why students in the class believed that they would get accurate scientific data from an experiment if they followed the right procedure. The following excerpt illustrates what the students thought were similar and/or different in both activities:

> 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.
> 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 1: They are similar because they both help us use formula to solve physics problem. They are different because of the interactions. It is because in the experiment we are among other people; like we are able to help each other figure out. The other way is just individual.
> 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 2: They are different because in the experiment you actually get real data but at problem solving you are just making it up to solve formula. Similarity can be to do the math. To do the math in the experiment is with real data and in the problem solving it is maybe real or make up data.

To sum up, the analyses revealed that the students in this class activated practicing formula epistemological resource in two activities as similar in some ways. They viewed that both activities were similar because they followed the same procedure and did the same thing. Students reported that in the laboratory activities after they collected data, they followed the same mathematical procedure in which they used to do in the problem-solving activities. Some students also pointed out some differences between the problem-solving activities and the laboratory activities. Student 1 mentioned that both activities created different learning environments, where he viewed the problem-solving activities were more individual and the laboratory activities were more interactive. Student 2 also mentioned that to practice a formula in the laboratory activities, they used real data, whereas in the problem-solving activities, they used make-up data. One noteworthy point in the students' responses is that they viewed both activities similar in terms of what they were doing and how they were approaching the scientific problems in physics.

5 Discussion

5.1 Conclusions

There have been few previous studies on students' personal epistemologies in school science practices. In this study, our purpose has been to describe students' personal epistemologies in school science practices and how they mobilized their personal epistemologies in the teacher-directed instruction and in the student-directed instruction.

The findings of this study are consistent with previous studies on students' ideas about the relationship between scientific theory and experiment. Ibrahim et al. (2009) found that, typically, undergraduate physics students considered experimental results as more accurate than theoretical results, and scientific experiments were required to provide evidence about the phenomena being investigated in physics. In addition, Driver et al. (1996) reported that students aged 16 were more likely to view experimentation as the only way to test ideas in science. Unsurprisingly, the students in this study mentioned that theories must be tested to go beyond being an idea or a thought. The participants of the present study seemed to use relation-based reasoning defined by Driver et al. (1996). In relation-based reasoning, the purpose of a scientific experiment is to identify the relationship between the variables. This study went beyond that to identify students' epistemological resources activated in evaluating scientific theories.

In addition to this, one interesting finding from this study is that some students activated different epistemological resources to justify scientific theories. That is to say that although students 1 and 7 defined a scientific theory as an idea or a thought that needed to be tested, they considered Einstein's theoretical explanation as more convincing than Galileo's experimental explanation and Aristotle's theoretical explanation. This is notable because this result suggests that how students evaluate specific scientific theories differ from how they define scientific theories in general at the interviews. This also supports our argument mentioned at the beginning of the study that the decontextualized interviews may be insufficient to map the students' personal epistemologies (Leach et al. 2000). This result is also in line with the findings of previous studies on students' epistemic judgments. The previous studies in students' epistemic judgment reported that their judgments have been inconsistent across contexts (Driver et al. 1996; Leach et al. 2000; Sandoval and Cam 2011). Sandoval and Cam (2011) argued that the inconsistency among students' choices might be explained by the epistemological resource framework defined by Hammer and Elby (2002). They asserted that, while students in their study judged the scientific claims, they seemed to trigger epistemological resources such as *claims are more believable with evidence*, *causal mechanisms must be plausible*, and *authorities are less persuasive than evidence*. The results of this study indicate that the students in this study triggered different epistemological resources across scientific explanations. Future studies on personal epistemology and/or students' epistemic judgments should consider the epistemological resources framework to explain the inconsistencies at students' choices.

The results of this study support the results of previous studies that discuss the problems associated with the traditional laboratory activities in a high school classroom (Brown et al. 1989; Samarapungavan et al. 2006; Tobin and Gallagher 1987). Previous studies have documented that students typically described their laboratory activities as simple and highly structured. They also 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 began conducting them. In addition, the teacher who has been observed in this study provided hints to his students in order for them to "correctly" do the calculations. Chinn and Malhotra (2002) argued that simple inquiry tasks are so simple that students barely think that they would find flaws in their experiment or even they do, they think that it is because of the mistakes they did. The findings of this study provide evidence that when students are given all necessary procedures for an inquiry task, they tend to trigger the epistemological source of the accuracy via following the right procedure. In addition to this, our analysis revealed that students activated another epistemological resource to evaluate the accuracy of their data. We call this epistemological resource as *accuracy* via *what others find*. This epistemological resource is important because it prevents students from thinking about the nature of scientific data and objectivity of data in scientific knowledge construction.

This study suggests that traditional formula-based instruction leads students to develop an idea that a problem in physics has either a correct or a wrong answer. Muis (2004) argued that teaching strategies that focus on accuracy and memorization of rules and procedures are associated with the beliefs that there is only one right answer, that knowledge is unchanging, and that knowledge consists of isolated pieces of facts. In this context, the teacher is the source by which to justify knowledge. This study provides evidence of how experiments that were used for refuting scientific theories in physics conceal the epistemological aspects of scientific practice reported by studies on sociology of science (Lave and Wenger 1991). Furthermore, Sin (2014) argued 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 make students aware of sociological aspects of physics and the epistemological implications related to how knowledge claims have been validated (Sin 2014).

5.2 Educational Implications

Opposite to traditional views on epistemological sophistication, the epistemological resources framework defined by Hammer and Elby (2002) focuses on the varied epistemologies that students employ as they participate in an activity. That is to say that rather than classifying students' descriptions on the nature of scientific knowledge as naïve or sophisticated, the epistemological resources framework is concerned with students' use of those resources in productive ways in the particular contexts. Therefore, examining students' personal epistemologies in their practices of high school physics in terms of epistemological resources framework have important implications for physics and science teaching in school settings.

The epistemological resources framework asserts that students can use different epistemological resources (ranging from naïve to sophisticated) in different settings. If teachers are aware of what particular epistemological resources that students activate in the classrooms, then the teacher can provide them with opportunities to use more sophisticated epistemological resources that students are aware but fail to activate (Elby and Hammer 2010). For example, the findings of this study revealed that students considered project-based investigations as having multiple answers. They mentioned that if an investigation had multiple answers, they did not expect to get the same answer. This result suggests that students are able to distinguish between the experiments they conduct in terms of their characteristics, for example, concerning whether the experiment is simple or complex. The nine students in this study did not view all experiments as the same. This result is aligned with the findings of previous studies. The previous studies that investigated the impact of students' personal epistemologies on school science practice have reported that the students' personal epistemologies are localized and fragmented (Sandoval and Reiser 2004; Hammer et al. 2005; Rosenberg et al. 2006). The experiments that students completed in this study were simple and not complex or open-ended ones. We were not able to thoroughly investigate our students' performance in all experiments including project-based investigation. However, our analyses of their responses in the interviews indicated that our participants would not use naïve epistemological resources such as *accuracy* via *following the right procedure* or *accuracy* via *what others find.* This indicates that our students may have activated sophisticated epistemological resources in more open-ended tasks.

Additional to this, many scholars recommended that school science laboratories should reflect the epistemological aspects of authentic inquiry experiences (Chinn and Malhotra 2002; Sin 2014). To foster epistemological understanding, it is important to integrate epistemological views with science content (Kittleson 2011). One implication relates to Koponen and Mantyla's (2006) idea of generative justification of knowledge. With generative justification of knowledge, with insights from history and philosophy of physics, Koponen and Mantyla suggested that experiments should be the source of new knowledge rather than simply re-doing historical experiments at school. With such educational approaches that help students understand the epistemological aspects of the experiments, students may be able to make better judgments to approach experiments in physics and activate sophisticated epistemological resources over practicing formula (Chinn and Malhotra 2002; Koponen and Mantyla 2006).

5.3 Limitations of the Study

This study has several limitations. First, the school policy did not allow students to be video-recorded; thus, the students' conversations were only audio-recorded. This precluded us from analyzing the students' visual clues in their interactions with others in the classroom. To minimize the effect of this missing data, the first author observed students' practices in the classroom. Second, there were limited interactions among students during the laboratory activities. Their conversations might have provided limited clues on their epistemological thinking. To overcome this issue, informal and post-activity interviews were done. Finally, the epistemological resources that students activated were examined only in the traditional instruction. Examining epistemological resources in different settings (e.g., STEM-based and traditional instruction) may depict the better illustrations of the context-dependency of the epistemological resources.

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Compliance with ethical standards

Conflicts of interest None.

Appendix

Interview Protocol

Time and data of interview:

Place:

Interviewer:

Interviewee:

Research Questions: What are the epistemic views that students hold?

Questions (The questions below will guide the conversation, as needed emerging questions will be asked):

Probe- Certainty of scientific knowledge:

To what degree students believe that scientific knowledge is certain versus fluid and tentative?

1. Do you think that scientific knowledge about …. (physics subject that being covered) in textbooks (teachers and scientists) always true?
2. How do scientists know if they are right about something?

Probe- Simplicity (Development) of scientific knowledge:

To what degree do students believe that scientific knowledge consists of an accumulation of facts or a system of related constructions? What do students think about how scientific knowledge and theories have been developed?

1. What is experiment? Why do scientists do them?
2. What is a theory? After scientists have (had) developed a theory, does the theory ever change? What kind of change may occur in the development of science? How and why?

Probe- Justification of knowledge:

To what degree do students think the role of evidence to evaluate scientific knowledge claim?

1. What is evidence? What is the role of evidence on scientists' claim?
2. What is your understanding of the word "data"?
3. Do you think your friend should reach the same results that you have found in your experiment? (scientists, too)
4. Is it possible that the same results are interpreted differently by different scientists?

Probe- Source of knowledge:

To what degree do students see scientific knowledge as transmitted from external sources or internally constructed?

1. Do you think we have to believe what textbooks say about …. (physics subject that being covered)?
2. How do you know this equation or etc.? (showing a formula from the textbook) If you had to teach this … to someone, how would you do that?
3. Where do you go when you have questions about a scientific issue? What do you do if you find a disagreement among sources?

Post-activity Interview Questions:

1. How do you prepare for the lab?
2. How do you define the purpose of the activity?
3. Do you think that there is anything that you find it for sure in your activity?
4. What do you do when your results do not match the expected results from the theory?
5. How do you draw conclusions from the experiment?

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