Secondary Science Teachers' Use of Laboratory Activities: Linking Epistemological Beliefs, Goals, and Practices

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ABSTRACT: The purpose of this study was to explore how science teachers' epistemological beliefs and teaching goals are related to their use of lab activities. Research questions include (a) What are the teachers' epistemological beliefs pertaining to lab activities? (b) Why do the science teachers use lab activities? (c) How are the teachers' epistemological beliefs and instructional goals related to teaching actions? Two major aspects of epistemologies guided this study: ontological aspect (certainty/diversity of truth) and relational aspect (relationship between the knower and the known). The ontological aspect addresses whether one views knowledge as one certain truth or as tentative multiple truths. The relational aspect addresses whether one views him/herself as a receiver of prescribed knowledge separating self from knowledge construction or as an active meaning maker connecting self to the knowledge construction processes. More sophisticated epistemological beliefs include the acknowledgement of multiple interpretations of the same phenomena and active role of the knower in knowledge construction. Three experienced secondary science teachers were interviewed and observed throughout an academic course. The findings illustrate that a teacher's naïve epistemological beliefs are clearly reflected in the teacher's teaching practices. However, a teacher's sophisticated epistemological beliefs are not always clearly

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connected to the practice. This seems to be related to the necessary negotiation among their epistemological beliefs, teaching contexts, and instructional goals. Ontological and relational beliefs seem to be connected to different facets of teaching practices. Findings indicate that various syntheses of different aspects of epistemological beliefs and instructional goals are linked to teachers' diverse ways of using lab activities. Implications for research and teacher education are discussed. *Sci Ed* **89:**140–165, 2005

INTRODUCTION

For decades, many research studies have focused on identifying teachers' knowledge and beliefs and understanding how they affect teaching actions (Calderhead, 1996; Clark & Peterson, 1986; Munby, Russell, & Martin, 2001; Tobin, Tippins, & Gallard, 1993). The research findings demonstrate that teachers develop knowledge and beliefs as they experience teaching, and their knowledge and beliefs may or may not directly affect their teaching actions (Brickhouse, 1990; Tobin & McRobbie, 1996; Lederman, 1999; Lederman & Zeidler, 1987). Research identifies and elaborates the myriad factors that shape what teachers do in the classroom. Some of these factors include goals for student learning, teaching contexts, and beliefs about students, the nature of science, and the curriculum (Cornet, Yeotis, & Terwilliger, 1990; Gallagher, 1991; Gess-Newsome & Lederman, 1994; Lakin & Wellington, 1994; Schoenfeld, 1998; Tobin & McRobbie, 1996; Tobin, McRobbie, & Anderson, 1997). Given the numerous factors, research reports inconsistent results about the relationship between beliefs and teaching practices indicating that teachers' beliefs do not necessarily have a direct causal bearing on teachers' actions (Tobin, Tippins, & Gallard, 1993).

The studies about teacher beliefs and actions provide background knowledge for a next step for further understanding of teaching practices. Many previous studies provided rich descriptions about teachers' beliefs and actions, and illuminated the area of reform-practice gaps (Brickhouse, 1990; Cronin-Jones, 1991; Gallagher, 1991; Olson, 1981; Yerrick, Park, & Nugent, 1997). These studies found that teachers' espoused beliefs and intentions often stand in contrast to their classroom teaching actions. Based on the previous research findings about the influencing factors, the current study attempted to understand teacher's teaching practices by exploring connections among descriptive pieces such as goals and epistemological beliefs from the emic perspective. In other words, we tried to understand how teachers make sense of their teaching practices and characterize their own practices in terms of the shaping factors identified in the literature. In so doing, this study focuses on why teachers adopt different teaching practices in their particular teaching contexts, possibly according to different combinations of those pieces. By linking these diverse influences on classroom practice, this study will complement a body of literature on teacher beliefs and practices, and perhaps aid researchers interested in creating explanatory studies with specific constructs.

Among the many areas of teacher beliefs, this study focuses on how teachers relate their instructional goals and epistemological beliefs to their teaching practices, consistent with the main thrust of the current reform agenda (American Association for the Advancement of Science (AAS), 1993; National Research Council (NRC), 1996). Moreover, we have focused our study of teachers' teaching actions around laboratory activities due to the unique importance of the laboratory to science teaching. First, lab activities are central parts of knowledge construction in science and hence, an essential area for identifying epistemological beliefs underlying teaching actions. Second, there is a lack of research on teachers' ideas and actual use of lab activities. For more than a century, lab activities have been used in science teaching as essential classroom activities (DeBoer, 1991). In promoting lab activities over the years, there have been a series of rationales for their use, as well as taxonomies of types (Bates, 1978; Hodson, 1993; Lazarowitz & Tamir, 1993). However, the effectiveness of the use of lab activities in school science learning has not been clearly demonstrated (Welch et al., 1981; Wellington, 1998). In the midst of researchers' continuing arguments for the use of laboratory, teachers' voices have often not been heard. More information on teacher beliefs about, and use of, lab activities will inform a better way to support teachers' effective use of lab activities.

The purpose of this study is to explore how experienced secondary school science teachers' epistemological beliefs and instructional goals shape their use of lab activities. This study answers three research questions: (a) What are the teachers' epistemological beliefs pertaining to lab activities? (b) Why do the science teachers use lab activities? (c) How are the teachers' epistemological beliefs and instructional goals related to their teaching actions?

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

Epistemology is a philosophical study of the nature of knowledge and knowledge development. Personal epistemologies or epistemological beliefs refer to beliefs about the nature of knowledge and ways of knowing (Hofer & Pintrich, 1997, 2002). A growing interest in epistemologies in education can be traced back to Perry's (1970) seminal work of college students' interpretation of their educational experiences, Kuhn's (1970) explication of the development of scientific theories, and Schwab's (1962) promotion of inquiry science. In Perry's study, college students demonstrate a progress from simplistic to more sophisticated epistemological beliefs. Their simplistic epistemologies include beliefs in certain and absolute knowledge and separation of the knower from knowledge authority (dualism). These naïve epistemological beliefs become more sophisticated through the recognition of multiple interpretations of the same phenomena and acknowledgement of the value of personal meaning construction instead of receiving prescribed knowledge (multiplicity and relativism). Eventually, they become able to evaluate different interpretations in relation to contexts (contextualism). In a similar vein, Kuhn illuminated multiple interpretations in science such as theory-laden data processes that occasionally delayed scientific revolution. A view of science as an "objective" true representation of reality turned out to be a naïve image (naïve realism). In this naïve view, scientific knowledge is believed to mirror reality that can be exposed directly to human senses. In contrast, in a more sophisticated view, science theories are seen as human explanations of natural phenomena produced through rigorous scientific inquiry. The existence of multiple interpretations and multiple theoretical constructions of the same phenomena brought a view of science as being tentative and "fluid" (Schwab, 1962) meaning that science knowledge is a tentative and evolving truth rather than the fixed and absolute truth. Schwab argued that science teaching should address evolving nature of science and need to take the form of science inquiry.

The seminal and subsequent studies (Belenky et al., 1986; Elby & Hammer, 2001; Kuhn & Weinstock, 2002) suggest two major aspects of epistemologies: ontological aspect (certainty/diversity of truth) and relational aspect (relationship between the knower and the known). The ontological aspect addresses whether one views knowledge as one certain truth or as uncertain multiple truths. The relational aspect addresses whether one views him/herself as a receiver of prescribed knowledge separating self from the sense-making processes or as an active meaning maker connecting self to the knowledge construction processes. More sophisticated epistemological beliefs include the acknowledgement of multiple interpretations of the same phenomena and active role of the knower in knowledge construction. These two aspects have guided this study throughout. If a certain teacher has more sophisticated epistemological beliefs, the teacher would encourage students to make meanings on their own and to bring students closer to science through engaging them in doing science for themselves. In that case, the teacher would present science as tentative knowledge and emphasize a process of meaning making more than the result.

Epistemological beliefs have gained renewed attention in science education as the current reform promotes epistemological shifts in both content and methods of teaching (AAAS, 1993; Millar & Osborne, 1998; NRC, 1996). Curriculum reform documents require teachers to depart from the traditional transmissional teaching mode to constructivist teaching in which students' multiple meaning constructions are acknowledged, and understanding of the nature of science through experience of science inquiry is promoted. Accordingly, much has been written about teachers' epistemological beliefs and their influences on teaching actions (Abd-El-Khalick & Lederman, 2000; Hammer, 1995, 1997; Hashweh, 1996).

Studies about teachers' professed epistemological beliefs support a possible relationship between teachers' epistemological beliefs and actions. For example, in his study, Hashweh (1996) directly asked teachers about their epistemological beliefs and teaching strategies. He reported that teachers' professed epistemological beliefs—view of knowledge and view of learning—were consistent with their preferred ways of teaching. In addition to the existence of possible connections between teachers' professed epistemological beliefs and teaching approaches, several studies describe how teachers' epistemological beliefs influence their instructional actions as well as the degree of consistency among teachers' professed epistemological beliefs and their actual actions in the classroom (Hillocks, 1999; Schoenfeld, 2002; Tobin, McRobbie, & Anderson, 1997). These observational studies found that the relationship between teachers' epistemological beliefs and their teaching practices was not a simple correlation; rather, their relationship was intertwined with other domains of teacher beliefs including beliefs about instructional goals, students, and teaching contexts (Gess-Newsome & Lederman, 1994; Schoenfeld, 1998; Tobin & McRobbie, 1996; Yerrick, Pedersen, & Arnason, 1998). In Yerrick, Pedersen, and Arnason's (1998) study, for instance, a high school physics teacher appropriates knowledge authority and excludes students' alternative voices for smooth classroom management and curriculum coverage. While the teacher smoothly manages the classroom to cover the state mandated curriculum, science is portrayed only as a predetermined and rigid body of knowledge. The findings imply that teachers may take a specific epistemological stance not only because of their epistemological beliefs but also because of practical needs such as instructional goals and classroom management. Further research on how these components are connected will shed light on teachers' instructional practices.

A few studies have focused on secondary science teachers' use of lab activities (Beatty & Woolnough, 1982; Tobin, 1986). In Tobin's (1986) study, lab activities were typically used as "a frill" that was not conceptually integrated with the science course as a whole. His study suggests that when teachers have naïve epistemological beliefs in which they consider knowledge as a transmittable entity, they view lab activities as an extra to the main lesson; they fail to see lab activities as opportunities for students to make meanings through scientific inquiry. This implies that teachers' epistemological beliefs influence their ways of using lab activities.

Previous research suggests connections between epistemological beliefs and practices and between teachers' instructional goals and practices on a macroscopic level. The present study explores the possible relationships among the three pieces on a microscopic level through investigating how each teacher synthesizes their beliefs and goals to produce their unique teaching practices. For this end, we identified teachers' specific epistemological beliefs, their purposes of using lab activities, and how they related those two to their teaching practices.

METHODS

This is a multiple case study (Merriam, 1998). Using the convenience sampling method (Patton, 1990) we recruited participants from a summer professional development workshop. The workshop was 1-week full day workshop on science inquiry, conducted by the second author. The purpose of the workshop was to have teachers explore their own definitions of inquiry-based science in a community of learners, rather than "teach" them inquiry-based approaches. As such, the workshop consisted of hands-on activities and discussions on the nature of inquiry-based learning. While we hoped the teachers would take some workshop ideas back to the classroom, we in no way anticipated that a 1-week experience would influence their core belief systems. Therefore, no attempt to directly "evaluate" the impact of the workshop on the teachers' practices was conducted as part of the current study. Rather, the main connection between the workshop and the study was that the former allowed us to establish close working relationships with the participants.

Among five volunteers from the workshop, teachers who had many years of teaching experience in high schools were included in this study. The other two teachers were first year teachers. Thereby this study examined three experienced high school teachers' use of science lab activities. By including only experienced teachers, we tried to eliminate extra factors originating from teachers' naïveté and identify stable relationships between beliefs and practices. We considered that first year teachers' lack of knowledge of students, schools, communities, and resources might shadow the relationship (Simmons et al., 1999).

Participants

Authors of this study first met the participants during the summer workshop. The second author was the instructor of the workshop while the first author met them only as a researcher. The teachers read a brochure mailed to their schools and applied for the workshop. By completing the workshop, the teachers received Staff Development Credit required by the state. Although we did not ask participants about the reasons for their participation in the workshop, they mentioned that they expected the workshop to be more interesting than other in-service courses.

The names of the participants are pseudonyms. Jerry is a male European–American with 17 years of teaching experience in high schools. Before he started teaching, he obtained a master's degree in ecology and had worked as a lab technician for several years. At the time of this study, Jerry was teaching 11th-grade chemistry and 12th-grade physics. He had been teaching the two subjects for the most of his teaching career. This study only reports his chemistry teaching.

Pamela is a female European–American with 16 years of teaching experience in middle and high schools. She has a bachelor's degree in chemistry. Before teaching, she had also worked as a lab technician for several years and stayed home for many years. She obtained a masters' degree in science education in the midpoint of her teaching career. At the time of the study, Pamela was teaching 9th-grade physical science, her main teaching subject for years. Jerry and Pamela were teaching in the same high school that was located in a working-class suburban/rural area in the southeastern USA.

Tom is a male European–American with 19 years of teaching experience in high schools. He has a bachelor's degree in science education. At the time of this study, he was teaching 9th-grade physical science that he had been teaching for years. Tom's school is located in a middle-class suburban area in the southeastern USA.

School Contexts

In general, students in the state are placed into one of three tracks: college prep, technical prep, and special-needs. During this study, Tom and Pamela were teaching physical science for technical prep, low-achieving students while Jerry's students were all college prep, high-achieving students. The high school where Tom was teaching had about 1,300 students enrolled. School records showed that 70% of the students went to college in the previous year. The high school where Pamela and Jerry were teaching had about 1,100 students. The majority of them came from low socioeconomic backgrounds. A very low percentage of students in the school went to college, according to Jerry. Both schools had about 10% ethnic minority students.

Data Collection and Analysis

Both authors of this study participated in collecting and analyzing the data. The data were collected during summer, 1999 and the following academic year, 1999–2000. Data sources for this study include formal and informal interviews, classroom observations, and teaching materials such as student worksheets and lab sheets. Data collection and analysis had two phases.

Phase I. The first phase includes initial formal interviews and the development of descriptive coding schemes from the interview data. A formal interview with each participant was conducted when the teachers visited the university campus for the workshop. The first author conducted all the initial interviews as a person who was irrelevant to the workshop. This was to prevent any bias from both the interviewer and interviewees.

The initial formal individual interview was a semi-structured format with an interview guide (Appendix A). We used open-ended questions about teachers' purposes of using labs (interview question 4), ways of using them (interview questions 1–3) and two "critical incidents" developed by Nott and Wellington (1995). Normally, people do not reflect explicitly on their epistemologies (Hammer & Elby, 2002). Instead of direct questions about the nature and development of science knowledge, therefore, we chose to use critical incidents as a tool to identify teachers' epistemological beliefs in relation to lab activities. Critical incidents are events in which teachers need to decide on spontaneous actions that illuminate teachers' epistemological beliefs (Nott & Wellington, 1995, 1996). Research findings indicate that teachers' responses to critical incidents help teachers express their epistemological beliefs. Moreover, by using critical incidents of lab activities, we were able to focus on epistemological beliefs within the context of science lab instructions and in particular, physical science lab activities. Contextualizing the questions about epistemological beliefs is consistent with research arguments about domain specificity of epistemological beliefs (Hammer & Elby, 2002; Hofer, 2000; Kuhn & Weinstock, 2002). These interviews lasted about an hour and a half for each participant.

Using constant comparative analysis (Strauss & Corbin, 1990), both researchers jointly developed descriptive codes from the initial data and categorized them across cases. The categories included teaching goals, teaching strategies, beliefs about science, learning, and inquiry, and beliefs about students (Table 1). These categories provided bases for subsequent data collection such as observations and additional interviews (Blumer, 1969). Initially, we discussed our coding categories and created initial belief profiles for each participant. Subsequently, we looked for confirming or disconfirming data during observations and following informal interviews. For example, during the initial interview all the teachers mentioned that the purpose of labs was to challenge students' prior ideas. In the subsequent data

TABLE 1
Data Summary (Phase I). Descriptive Data Codes from the First Formal Interview

Initial Categories	Codes
Teaching goals for labs	To develop cognitive skills and engage students cognitively; to challenge students' alternative conceptions; to reinforce information; to teach manipulative skills.
Beliefs about students	Students have alternative conceptions; students want the right answer; students tend to play in labs; students have different cognitive levels; students think science is difficult to learn.
Teaching strategies	Some labs need background knowledge; using hands-on depends on resources, working labs, and expected learning outcomes; lab structures depend on topics; using counterintuitive activities; labs trade off time and content.
Beliefs about science	Science has logic and fun; science is content and skills; science is in everyday life.
Beliefs about learning	Need sensory experiences to understand; need reinforcement.
Beliefs about inquiry	Problem-solving; having various answers; counterintuitive lab results encourage students to think; some inquiry labs require prior understanding; lab results need to be consistent with previously accepted knowledge.

collection, we tried to identify whether the teachers used lab activities as a tool for assisting students' conceptual change or presenting phenomena for discounting students' prior ideas. We anticipated that those two different ways were related to their epistemological beliefs underlying their use of lab activities. In another example, none of the teachers explicitly mentioned inductive activities as a type of lab strategy. In subsequent data collection, we carefully observed the structure of each lab activity in search for any inductive portion of lab activities.

Phase II. The second phase of data collection and analysis include observations and informal and formal interviews. Following the first formal interview, participants' classroom teaching was observed during the period of one complete course. The observation was in a non-participant format. The observation schedule was set up as each teacher informed us of the dates of lab activities. Schools of the participants had 90-min class periods, which allowed us to observe pre- and post-lab lessons in addition to actual lab activities. On average, participants used lab activities once a week (20% of course hours), but occasionally the teachers cancelled activities indicating that some lab activities were expendable in teaching. We were able to observe eight, eight, and five class periods for Jerry, Pamela, and Tom respectively prior to finding repetitive patterns. Tom used the least number of labs and he did not invite us to observe lessons with only demonstrations. Except for initial observations for each participant, all observations were video recorded and transcribed for analysis (Table 2).

We also took field notes during observations. For consistency in observational data collection between the two researchers, both authors made initial observations together for each participant. We identified common foci for observations including teacher's movements, general classroom tone, teacher reaction to students' answers, overall class proceedings, board or overhead work, and lab instruction sequences. Each researcher's field notes,

TABLE 2
Video Recorded and Transcribed Lab Activities

Teacher	Lab
Tom	Classification, Bottle Rocket design, Conductivity and chemical bonding, Solutions, Solubility
Pamela	Dry ice[a], Density, Atom model, Penny alloy[a], Heat conduction[a], Chemical change[a], Acid and base[a], Natural gas[a]
Jerry	Periodic properties, Percentage composition, Conductivity and chemical bonding, Molecular model, Can crush, Boiling and freezing points, Specific heat, Stoichiometry, Ideal gas constant

[a]Demonstration

therefore, contained information on those aspects of teaching. However, there was no formal observation form. After the initial common observations (2–3 common observations for each participant), each researcher observed different participants. The first author observed most of Jerry's lessons while the second author observed Tom's and Pamela's lessons. Consequently, the first author conducted a final formal interview with Jerry while the second author conducted final interviews with Tom and Pamela. Between the two authors, all field notes were exchanged for separate analyses as soon as each one was completed. Videotapes were exchanged based on the needs for clarification of field notes.

After each observation, we implemented informal interviews regarding the lab session, the previous lesson, and plans for the subsequent lessons. The informal interviews lasted from half an hour to one hour, depending on the questions emerging from the observation. Most of the informal interviews were concerned about how the teachers related lab activities to student learning in order to find how teachers related epistemological beliefs and goals to their practices. During the informal interview, for example, Tom was asked, "When do you use demonstrations?" Pamela was asked, "What did your students learn from making models of atoms?" Jerry was asked, "Why did you use two similar tests?" We used lunch hours, planning periods, or after-school hours for the informal interviews. Through the informal interviews, we also identified overall lesson plans for their entire courses.

After all observation data were collected, final formal interviews were conducted in order to clarify and refine the data from the observations and interviews. We brought codes and themes emerging from the data in order to check their agreement with our analysis (member checks). Interview questions for each teacher varied depending on the data emerging from each of them. Nonetheless, common questions about teachers' epistemological beliefs and goals were asked (Appendix B). Most interview questions concerned both goals and epistemological beliefs. Rapport built during observations and informal interviews enabled us to ask them directly about their epistemological beliefs in relation to student learning (final interview question 6). The final interview lasted about one and a half hour for each participant. The total numbers of interviews were ten, eight, and seven for Jerry, Pamela, and Tom respectively. All of the formal interviews and some of the informal interviews were audio recorded, transcribed, and analyzed.

The second phase of data analysis was aimed at finding patterns in the teachers' teaching actions and links to their beliefs and goals. The six descriptive categories drawn from the initial interviews were refined through our interpretations and teachers' explanations of their own teaching actions (Table 3). Epistemological beliefs were refined to two subcategories: ontological and relational beliefs for each teacher. Teachers' espoused goals were sorted and sifted in search for their connections with teaching actions (Miles &

TABLE 3
Data Summary (Phase II). Teachers' Differences in Their Epistemological Beliefs and Goal(s) in Using Lab Activities

Domains	Pamela	Tom	Jerry
Epistemological beliefs			
Ontological aspect			
	Science is a body of knowledge as facts.	Science is both a body of knowledge and a diverse way of problem solving; an objective truth and relative subjective truths coexist.	Science is scientists' tentative explanations validated through rigorous inquiry processes; truths of scientific explanations depend on contexts. Science is not tentative in the school context.
Relational aspect			
	Both the teacher and students are consumers of science. Students receive information from a source.	Everyone can do science; students are scientists through engaging in problem solving.	Students need to accommodate the scientific way of thinking through replication of scientific processes.
Primary goal and student needs			
	To inform students.	To engage and to inform students.	To help students appreciate science.
	Students need information.	Students need emotional support and information.	Students need to understand the scientific way of thinking.
Use of lab			
Type of lab			
	Demonstration using Prediction-Observation-Explanation approach in place of student lab.	Open-ended lab and structured lab	Highly structured lab
Role of lab			
	To prove the verity of the scientific knowledge; to provide the opportunity to apply the concepts.	To motivate students; to provide firsthand experience to assist learning.	To train the scientific way of thinking; to prove the explanatory power of scientific theories.
Classroom management			
	Encourages students' participation through low cognitive demands (predictions and observations).	Allows students' diverse methods and answers in solving problems.	Uses structured and authoritative classroom management.

Huberman, 1994). Using the properties of epistemological beliefs, goals, and teachers' use of lab activities, we developed a conceptual map for each teacher in order to answer the third research question, the connections among epistemological beliefs, goals, and actions. During the final stage of data analysis, we focused on understanding why the teachers demonstrated different ways of teaching and use of lab activities in particular. Throughout the second phase of data collection, the two authors met to share each one's tentative data analyses whenever new findings emerged and developed shared interpretations throughout.

Trustworthiness

Throughout data collection, we utilized multiple researcher triangulation. Both authors analyzed the data separately and then compared the tentative interpretations to develop a shared understanding of the data. For example, all participants stated that they consider their students' prior knowledge in teaching and both authors agreed that each teacher used different words ("preconceived notion," "experience," "counterintuitive or intuitive ideas") in reference to students' prior knowledge. The triangulation analysis was primarily based on coded transcripts and other text-based data.

We also triangulated data from multiple sources. What participants espoused during the interview, the way they acted in the classroom, the teachers' explanations of their actions, and their curriculum materials were compared for each participant in order to find consistent themes across the different types of data. During informal interviews and final formal interviews, we also conducted member checks and obtained participants' confirmation on our data analysis.

FINDINGS

Before we present findings from the final analysis, it is worth mentioning the critical incidents used as a tool for identifying teachers' epistemological beliefs. In response to the two critical events (Appendix A) in which students failed to obtain expected data, all three teachers unanimously mentioned that they would evaluate equipment or students' process skills and "talk [their] way through it" (Nott & Smith, 1995). They expressed a belief that lab activities were to produce lab results that would be consistent with canonical science; lab was for verification. None of the teachers mentioned the possibility of discussing with students the relationship between knowledge claims and evidences collected during experiments. They all acknowledged the importance of repeating the same experiments but the repetition was only to have "correct" results; no one mentioned students' active negotiation processes in making sense of the unexpected lab results. The teachers' responses to the critical incidents initially led us to conclude that all three teachers had naïve epistemological beliefs—science is a body of knowledge and lab results are either right or wrong. However, observation data revealed notable differences in teaching actions demonstrating differences in their epistemological beliefs. We believe that the critical incidents used in our interviews asked only about close-ended lab activities resulting in activating teachers' epistemological beliefs only in that context. This preliminary finding confirmed the argument that beliefs activated into actions depending on contexts (Hammer & Elby, 2002; Schoenfeld, 1998).

In the following sections we present epistemological beliefs, goals, and the connections between beliefs and actions for each participant. Just as our preliminary finding has shown, epistemological beliefs and goals are context specifically activated. Hence, our findings may be part of the whole, activated by the context of science teaching of each participant.

Pamela

Epistemological Beliefs in Using Lab Activities. For Pamela, science is a body of factual knowledge to be obtained and used; she never questioned the verity of science knowledge and never referred to thinking processes involved in lab activities. During lessons Pamela frequently presented science as facts emphasizing that "science tells us how things work" (field notes). The purpose of demonstrations and labs, she mentioned, were to convince students of the truth of what she was teaching: "I tell them [and] I give them examples but they probably don't really believe me. And this would be a really good use of a lab" (interview, 3/16). Moreover, she never noted the possibility of multiple interpretations of the observed phenomena. In explaining her ways of using demonstrations and labs, Pamela mentioned only student observations of the phenomena and neglected students' cognitive processes involved in the interpretation of observation. Without consideration of cognitive processes, she used demonstrations and labs only to show natural phenomena. Pamela seemed to demonstrate a naïve realistic view that scientific explanations mirror physical phenomena.

Pamela's exclusion of the cognitive process seems to be relevant to the relational aspect of her epistemological beliefs. She viewed herself and her students as consumers who accepted given information without processing underlying principles. In an interview (10/7) Pamela mentioned, "I enjoy science because I want to know how things work. . . . I've seen the development of television, antibiotics, lasers. . . " and she added, "I became a teacher because I need to explain what I have learned." Given the relationship between science and the learner, Pamela conceptualized teaching as passing a body of knowledge to students to assist them in becoming good consumers of science. In her beliefs, science learning was receiving information, and students were rarely connected to sense-making processes.

Pamela's answer to one of the final interview questions about the difference in the ways of knowing between scientists and students confirmed our understanding of her epistemological beliefs drawn from the observational data. Although the interview question, "Would you compare the way scientists work with the way students learn in science?" was about the process of knowing, she focused her answer on knowledge and even the interviewer rephrased the question later in two ways: "Do you think the way scientists build a theory is different or similar to the way that students learn theories?" and "How do you think students learn [scientific] explanations?" Pamela responded:

> Scientists are usually trying for new knowledge or greater depth of understanding. What the kids are doing (pause) I guess the same. . . For the scientists it may be new knowledge for our culture. For the kids it's new knowledge for them. . . I don't know. Maybe there's no difference. Maybe it's just different in degree. I've not thought about it. (In response to the rephrased questions) (Pause) [Students] need some background knowledge. You can't explain things in terms of atoms if they've never heard of atoms. Um, I guess the synthesis of what they observe. What they observe supports very likely some hypotheses that they have. (Interview, 3/16)

Pamela's epistemological beliefs included science as a body of knowledge lacking the process of knowing. Moreover, she believed that the scientific knowledge mirrors the observed phenomena and hence, an observation had only one interpretation that confirmed preordained knowledge. Therefore, neither questioning the verity of science nor entertaining multiple interpretations of the observed phenomena was necessary. In her lab, learning was simply observing and confirming hypotheses. Mere sensory activities become learning.

Goal: Developing Informed Citizens. Pamela's main concern was how much she was able to prepare students to live as informed citizens in the future. For this goal, she believed that demonstrations and lab activities served two purposes: efficiently delivering information and providing opportunities to apply the information to everyday phenomena. Pamela described what she expected her students to accomplish in her class:

> I want them to go out into the world with an understanding of these topics. Um, there are some [topics] that I have covered more than others. I don't think any teacher covers the nuclear chemistry. I think going out into the world then you need to know what it is, what you can do, what you can't do, what to fear, and what not to fear. So I always felt this crazy desire to get as much knowledge into their heads as possible. (Interview, 3/16)

According to Pamela, students should have a wide range of information as consumers of science. Therefore, her primary teaching goals were to provide information as much as possible and to encourage students to utilize the information (interview, 3/16).

In the same vein, Pamela felt rewarded for her teaching whenever she found her students applying the information learned to describe phenomena:

> I always like the gold penny thing. I didn't announce we were doing an experiment with alloys. I just said, "Okay, we are going to do an experiment." . . . I never told them we alloyed it. They told me that was an alloy. Sooner or later somebody figured that out. We had already covered the subject. (Interview, 3/16)

Consistent with her epistemological beliefs, Pamela's teaching goal included only a body of knowledge and excluded thinking processes or decision-making skills. Her labs or demonstrations were for receiving and utilizing information rather than processing information.

Connections to Action. Pamela used many demonstrations in place of student lab activities because she believed that demonstrations efficiently served her primary goal, preparing informed citizen (interview, 6/30). Through demonstrating phenomena, she ensured enough time to deliver information while convincing the truth of the information and providing opportunities to utilize information (interview 3/16). Her beliefs about science as factual knowledge and students as consumers of science were consistent with her goal of delivering information.

In this section, we present Pamela's typical routine in her use of demonstration in order to illustrate the relationship among her epistemological beliefs, goals, and actions. Typically, after an introduction of concepts in lecture, Pamela demonstrated a series of phenomena related to the concepts. She usually solicited students' predictions and often let students vote on the best possible prediction. After students had seen the phenomenon, Pamela asked students to explain why it happened. The following vignette is based on an observation of her lesson on heat conduction:

> After about ten minutes of a lecture on metals, Pamela introduces a demonstration saying, "We're going to look at some conduction by metals." Pamela shows students a device called a conductor meter that has a wheel shape with five branches. She draws its shape on the blackboard and explains how it works. "Each of these branches is made of different kinds of metal. What we are going to do is to figure out which one conducts the best." She continues, "Okay, this one is made of steel, this one is copper, this one is brass, and this one is aluminum. What is Ni?" Many students answer, " Nickel." Pamela continues to explain, "So this one is made of nickel. Now each of these is supposed to have the same length and the same diameter. I have some wax. What I am doing is putting a little of that on the end of each of these branches. Then I am going to light the burner and hold it over the

> center of the burner. Actually, I think I can get a volunteer to hold it over the burner." Many students raise their hands and Pamela quickly chooses one of them. "Let's take James. Put the goggles on. Okay. Now, how we are going to know which one of these heats up first?" A student answers her question but it is not quite what she wants. She rephrases her question, "Which one of the wax pieces will fall off first? The pieces of wax will fall off when it gets hot." Many students give answers at the same time, and one student suggests voting on their predictions as they did before. Pamela tallies students' votes on the board and lets James hold the conductor meter over the flame. While all of them are waiting for the results, Pamela explains about control variables in experimental design and the temperature of each color of the burner flame until the first piece of wax falls off. "Copper went first. Then aluminum." Some of students shout, "Yeah, I believed it was copper!" One student asks, "Where's brass?" Pamela replies, "Brass is here. It still holds it. Copper is now smoking. Nickel and steel are still cool. Oh, there went brass. Tell me what is this telling you about steel and nickel compared to copper and aluminum?" Jerome answers the question and Pamela sums up the demonstration using his answer. "Okay, Jerome says that steel and nickel do not conduct heat as well as copper and aluminum. And I believe our experiment has proven it. Steel is still hanging on there. (To James) Thank you. You did a beautiful job. (To the rest of the class) So on your paper in the margin, I want you to write this." Pamela briefly writes the results on the board and students write those down.

Through questioning and soliciting predictions, Pamela encouraged students to be involved in the demonstration. Moreover, she typically used volunteers to do demonstrations. Students were excited to see if their predictions were right. While waiting for the results, Pamela continued to provide relevant information, indicating that she was "a compulsive explainer" (interview, 3/16) as she described herself. Apparently, demonstration proceeded efficiently serving Pamela's instructional goal of delivering information.

Although Pamela involved a few students in the demonstration and class discussion, most of the students' involvement in the class was limited to cognitively low demanding tasks such as voting on predictions, listening to her explanations, and writing down the results. With a few correct answers given by the students, Pamela continued to proceed with her lesson while most students did not have the opportunity to apply concepts to explain their observations. For Pamela, a few students' "right" answers indicated their learning while wrong answers went unnoticed. Consistent with Pamela's epistemological beliefs, she proved the verity of scientific knowledge, and students received it while thinking processes involved in explaining the observed phenomena were not seriously discussed. For most of the students, demonstrations and lab activities were the teacher's show-and-tell.

Tom

Epistemological Beliefs in Using Lab Activities. Tom believed that science was both a body of factual knowledge and problem solving (interview, 6/30). He related the two aspects of science to his use of two types of lab: structured and open-ended labs. In congruence with his responses to critical incidents, in his structured lab, Tom depicted science as factual knowledge that had one right answer proven by experimental data. His structured labs were for verification, and students were not invited to evaluate data collected in the lab (interview, 6/30, 4/11). The following lab introduction demonstrates Tom's epistemological beliefs activated in a structured lab activity. Tom verbally explained lab procedures that were laid out in a lab sheet:

> You are going to make up a bunch of solutions. . . I will go through [lab procedures] real quick. . . All I want you to do is to take one spoonful of the chemical (ammonium nitrate) in a test tube (showing to student) this much, fill it up about half full of water, put a stopper

> on it, you shake it up real good and feel the test tube and tell me what happens. Just write it down. Ok? When you've done just put it aside. Pick up another test tube. On this one again fill about a third or half full of water. Come to see me. I will give you some sodium hydroxide. . . (Solution lab, 4/11)

The lab obviously demonstrates students that all chemicals act differently when dissolved in water. The ammonium nitrate dissolved and removed energy from its surroundings (an endothermic process) and all students reported that they felt cold when they touched the test tube after they shook it up. Students compared this data with sodium hydroxide that released energy in an exothermic process and with table sugar that did neither as it dissolved. Discussions about the lab results stopped when students reported the same results leaving the findings as facts. Tom provided everyday applications such as hand warmers and ice packs used by athletic trainers. In this lab, he presented science as a body of factual information and expected his students to observe the phenomena and passively receive the information. Students were not invited to discuss their interpretations of the data and hence, they were disconnected to sense-making.

In open-ended lab activities (classification and bottle rocket design), Tom demonstrated his view of science as problem solving that allowed multiple methods and even multiple answers. He emphasized to his students that science was not only getting the right answer, i.e., expected data, but also trying out students' ideas and constructing their own answers. The following discussion between Tom and his students during the rocket design lab demonstrates Tom's epistemological beliefs activated in an open-ended lab activity.

> Tom: We looked at Boyle's law, Pascal's principle, [and] whatever. We are going to finish it up with this rocket lab. . . . Up here in my desk I've got materials. We have tape, string. . . I've got a role of plastic bags up here if anybody wants it for parachutes. I'm going to give you about 35 to 40 minutes to design, construct your rockets. Work in pairs.
>
> Student 1: How do you make a parachute?
>
> Tom: You figure it out. It's your job. (To the whole class) This is your design. I am not going to tell you how to build your rocket.
>
> Student 2: Do we have to have a parachute?
>
> Tom: It's your rocket. (Bottle rocket design lab, 2/11)

In this lab, Tom expected his students to apply their knowledge to design water rockets that could fly far. With no procedural instructions, students in pairs discussed variables such as shapes and parachutes in relation to air resistance and the amount of water in relation to the volume and pressure of the air inside the bottle. During the lab, Tom walked around the class and asked questions to focus students' attention on relevant factors avoiding direct instructions. Later students launched their rockets and discussed critical factors for optimal results while Tom summarized their discussion.

In the open-ended lab activities, Tom argued, "students had more chance to use imagination, the deeper thinking other than just following the steps or recipe" (interview, 6/30). He believed that students were actively engaged in the process of knowing by developing "their own techniques, their own labs to try to solve the problem" (interview, 6/30). Tom played a role of a facilitator who provided students with opportunities to solve problems while guiding them with questions. Through this process, Tom believed, students were engaged in science by having "ownership of their lab" (interview, 4/11). In this context, he demonstrated sophisticated epistemological beliefs that acknowledged students' multiple ways of knowing and connected students to sense-making processes.

Tom's answer to one of the final interview questions confirmed our observational data on his epistemological beliefs. He focused on both knowledge and problem-solving process of science:

> Interviewer: When you think about scientists and what they do how is it similar or different to have kids putting together scientific knowledge?
>
> Tom: It's what I tell them first day. They are all scientists. They became scientists first time [they] asked somebody "Why are something this way?" . . . You have questions, then you answer. That is actual science. The only difference between a professional practicing scientist and kids is the fact that professional scientists may take it a step further. . . They are still going through the same process. (Interview, 4/11)

Tom believed that students were scientists when they were involved in solving problems and the only difference between the two was the depth of knowledge they reached through the process. He clearly divided science into two parts, knowledge and problem solving, and connected students to science through problem solving.

Goals: Delivering Information and Engaging Students. Tom's primary goal for science lab activities was different in his two types of labs. During the structured lab activity, Tom pursued a goal of informing students. He believed that students needed to learn factual knowledge for the state graduation test and that experiencing phenomena helped them to learn better (interview, 6/30). On the other hand, in his open-ended labs, Tom had a goal of engaging students in finding their answers to problems. He expected students to "use [their] own intuitions" and "create [their] ways" to solve problems (observation, 2/11). Fixed knowledge was set aside; instead, students were invited to create their ways to solve problems and even "ask their own questions" (interviews, 6/30, 4/11).

Tom related his emphasis on student engagement to his students' need for emotional support. He maintained that his 9th-grade students were in the process of adapting themselves to the high school environment and that they needed his support for that process. Tom argued, "A lot of the freshman stuff, the developmental stage, where I don't care what you do, those kids emotionally need extra time" (interview, 6/30). Tom also related his concern for student engagement to the fact that he had many low-achieving students who were "scared of science" (interview, 6/30). According to him, his low level students were "the ones that [he was] most concerned about" and he wanted to support their confidence in science through open-ended labs (interview, 4/11).

Connections to Action. Tom used structured labs and demonstrations to achieve his goal of delivering information (interview, 6/30). Similar to Pamela, his use of structured labs and demonstrations was consistent with his view of science as factual knowledge and students as passive information receiver. Occasionally, however, Tom used open-ended lab activities in which multiple methods and multiple answers were allowed. His use of open-ended lab activities was to engage students in science learning by empowering them as scientists. Tom related his use of open-ended activities to his view of science as problem-solving or inquiry processes (interview, 4/11).

We present Tom's use of open-ended lab activity and describe how his epistemological beliefs and goals are related to his use of open-ended lab activities. The following vignette is constructed based on field notes; direct quotes are from the video transcriptions of the lesson.

> Telling students to put away review sheets, Tom raises his voice with excitement as he introduces the lab activity. “We are going to do a lab. . . We’ll look at different ways to solve a problem, which scientists do in a lot of cases.” Tom explains that scientists classify things to simplify problems and to make them solvable. He provides examples in biology and geology in a story format. Then he gives a set of lab equipment to each group for a classification task. Tom asks students to classify the equipment into three, five, seven, and fifteen groups and gives lab sheets out. The lab sheet has two components: a paragraph of lab procedures and a data chart. After he reviews the names and usages of the lab equipment to be classified, Tom gives students 20 minutes to finish the activity. Students are grouped into three to four and work on the task. Tom walks around tables and checks each group’s progress. After 20 minutes, Tom asks each group to present their results. “Okay. What was the name of the group?” Lorie replies, “Stuff.” Tom says to the rest of the class, “Okay. Is it legal to have a catch-all-stuff group?” Several students argue for its justification and Tom expands on students’ responses. “Yes. Scientists do that all the time. One of the largest groups we are going to study this year is called the salt group. And basically, in chemistry, if they don’t know what it is but it has to do with salt they throw it into the salt group.” All the groups have taken their turns to present their classification results and Tom sums up with a final comment. “Now, we have all different sorts of categories. Which one is the right one, which one is the wrong one?” “They are all right,” Jamie shouts. “They are all right! Are there wrong ones?” The students reply, “No!” “The only way you can be wrong is when you have a metal group and you put the glass bottle in it. Now instead of having one or two ways to look at the problem we’ve got 20 or 30 different ways to look at it or to solve it. With 30 different ways to attack the problem, we have many more chances to solve it. . . That’s what keeps science amazing. . . I wanted to let you think a little bit and possibly even argue among yourselves. ‘This goes here; no I think it goes here’ by using your individuality; be able to show ‘Hey, I can think too.’ ”

Through seemingly chaotic and unbounded lab activities, Tom encouraged students to “use their imagination” as scientists do. By encouraging students to construct their own answers, Tom believed, he could reach students who were “scared” of science. He wanted to help students feel that they could learn and they could do science (interview, 4/11). His intention to engage students in doing science was consistent with his view of science as problem solving. Moreover, he believed that science was not special but what every student was able to do. By expressing such a belief in the classroom and by providing opportunities for students to develop their own answers, Tom tried to connect students to science.

Tom related his two different goals to his two types of labs after he had a structured lab on solubility. He reflected on his way of using structured lab as a way to transmit information and compared this with his open-ended activities:

> [In my other labs] students can see [that] other people get different answers by approaching with different methods. On this lab here today there’s not a lot of chance for independence on it. . . . Let them figure out “How can you make it dissolve faster?” I can probably run a lab that way. . . . I think [today’s lab format] works better. . . . [because of] the time constraint. I know how much more I’ve got to cover this year. (Interview, 4/11)

Tom sometimes chose a structured lab format for his goal of delivering information while other times he used open-ended lab activities for his goal of engaging students in doing science. Two distinct epistemological beliefs were demonstrated in his two different types of lab activities in order to achieve two different instructional goals, respectively.

Jerry

Epistemological Beliefs in Using Lab Activities. Jerry applied two distinctive epistemological beliefs to two contexts: science and science teaching. He espoused sophisticated epistemological beliefs about science when he described how science knowledge had been developed. He believed that there is no absolute truth and that science is scientists' interpretations of natural phenomena. Instead of providing scientific ideas as a matter of facts, Jerry frequently used phrases such as "Bohr says" or "What scientists say" demonstrating his view of science. In the final interview he clarified his epistemological beliefs about science:

> I am trying to teach [that] scientists don't say this is the truth. We say this is PART of the truth. . . . But it's valid. I use words carefully, and I want students to think about their meanings. It's not truth with a capital T as in definitely 100% completely correct but it is a good interpretation. It's just a scientist's idea. (Interview 2/18)

According to him, scientific knowledge is humans' incomplete explanations of natural phenomena that can be disproved by a better explanation. On the other hand, Jerry believed that incomplete models were useful in explaining phenomena depending on contexts. Jerry talked about why students still needed to learn Bohr's model even though it was proved to be wrong: "If all you care about is the mass of a handful of matter, do we really care what the ultimate structure of the handful is? And that's what I am trying to explain [to my students]. We use different models to convey different parts of information" (interview, 2/18). According to his beliefs, scientific explanations are valid because they were proven through rigorous procedures, but their validity depends on contexts. Obviously, he demonstrated contextualism in his ontological view of science.

Jerry's lab activities demonstrated the valid aspect of scientific explanations but never reflected the tentative aspect of science. According to Jerry, he used structured labs to help students understand why data supported the theory. All of his labs were structured to obtain definite results. Most of the time his lab sheets had two full pages of instructions on procedures and data analyses. Most students obtained the same data resulting in the same analysis "as long as they followed directions" (interview, 6/30). Lab procedures and results were either right or wrong. There were no tentative explanations. This was consistent with his responses to the critical incidents.

In Jerry's laboratory, students were expected to be passive learners because every step was prescribed for them to obtain "the right" results. During lab activities, Jerry privileged a specific way of thinking and doing science and guided lab activities through a series of questions to lead students to the same conclusion in one way. In many occasions, Jerry mentioned that "the scientific way is not the only way but the effective way" (observation, 9/21). He acknowledged the existence of multiple ways of thinking but never provided opportunities for students to entertain different ways of thinking in the lab. Students were encouraged to experience only rigorous procedures and evaluation of data to support a given theory.

Jerry confirmed our observational data analysis during the last formal interview. He boldly said that school science was totally different from real science and hence, his teaching of science was confined to accepted knowledge itself rather than creative meaning constructions.

> Science is trying to build on prior knowledge and discovering new things. The science that I teach is just to explain knowledge that already exists. . . . Therefore, we don't do any research. . . . What we are doing is really just rediscovering in a pretty structured manner what is already known. . . . So we are not really doing science. We are learning about science. (Interview, 2/25)

According to him, school science was about "knowledge that already exists" disconnected from students. In his view, scientists are the ones who construct new knowledge, while students are learning what has already been verified. Separating school science from "real science," Jerry conceptualized that lab activities were for students to follow scientists' lines of thinking in a specified way to reach "their" conclusions. In his view of school science, students are not expected to create their ways to find their own meanings. Students were connected to science only when they can follow the specified way of thinking during the lab.

Goal: Developing Appreciation of Science. Jerry's main goal for science teaching was to help students appreciate science. Through rigorous verification of scientific explanations, he validated scientific theories and wanted his students to appreciate their explanatory power. He related his primary goal to his view of science. Jerry believed that science knowledge had developed through rigorous tests and obtained valid status. To appreciate science, he believed, students needed to understand rigorous validation processes (interview, 6/30). In most labs, Jerry asked questions about lab procedures and data analyses to help students understand the relationship between data and theory. For example, in his conductivity and chemical bonding lab, students were asked to test electric conductivity in 16 different chemicals. Students were required to determine a bond type for each of them. The last question for students to answer in the lab report was "Explain why the deionized water and tap water had different conductivities" (Lab sheet, 10/14). Jerry's intent was to require students to understand the relationship between the data on conductivity and the nature of ionic bonding and how bonding theory could explain an observable phenomenon, conductivity (interview, 10/14). His lab activities were tightly connected to theories; students were asked to evaluate data with a given theory and to understand scientific logic. In so doing, Jerry believed, students would appreciate science.

Jerry also related his goal to his students' needs. He claimed that teaching students to appreciate science was more valuable than focusing on delivering factual information because the information would be useless for most of his students who would not major in sciences (formal interview, 6/30). All his labs confirmed that scientific theories effectively explained natural phenomena. Through obtaining predicted data or interpreting data using scientific explanations, students understood the validation processes and experienced the explanatory power of scientific theories. These experiences, Jerry believed, were more meaningful for his students because they would lead students to develop scientific way of thinking and to appreciate science (interview, 6/30).

Connections to Action. Mostly, Jerry used a lab as a culminating activity of a weeklong unit and introduced a few new concepts during the lab in relation to previously introduced concepts. Typically Jerry had 20–25 minute-long lab introduction explaining purposes of lab, procedures, and methods of data analysis. After his detailed lab introduction, students conducted the lab with minimum help from Jerry. The following vignette is a typical chemistry pre-lab discussion and lab introduction.

> Jerry begins class by going over homework problems. Jerry asks, "Number 38. Any volunteers?" One student answers, "3.856" and Jerry replies, "That's not quite what I want." Another student answers, "3.86 grams" and Jerry replies, "Good man. Decimal points are not that important. It can be 3.856 or 3.86. Both are acceptable on Friday's test. But you have to put the unit after the answer." After about ten minutes of homework review, Jerry starts to introduce the lab activity distributing lab sheets. "Okay. Today's lab is a fun lab." Students turn quiet but still some voices are heard. Jerry calls for students' attention,

> "Gentlemen." A student asks the others to be quiet, "Shhhh—." No sound is heard and everyone is looking at Jerry. Jerry starts talking, "You can probably guess if you happen to look at the title. It's about periodic properties. We're going to look at a few periodic trends in a few selected elements, mostly metals. I put new terms and new ideas for you in this lab to play with. So it must be interesting." Jerry reads lab instructions and elaborates lab procedures. "Number one, periodic trend and solubility... Okay. Number one is easy. Follow the instructions. Does anybody happen to know what H_2SO_4 is?" Many students answer him. Jerry demonstrates how H_2SO_4 acts on a piece of fabric and warns students to be careful about using it. He continues to explain the nature of chemicals for the lab. Then he introduces the lab equipment and finally reads the data analysis part of the lab sheet. "Page 804 of your textbook tells you how to make a good graph. It has to have a label and a title, and you have to identify the axis. The instruction tells you what axis to use to make density. Also, a good graph uses preferably the entire sheet of graph paper.... Questions about anything?" No student responds to him and the 25-minute long introduction to the lab ends. Jerry assigns lab groups and says, "Easy lab. Fun lab. Okay, go for it and have fun." Throughout the lab Jerry walks around each group and ensures that students follow the directions on the lab sheets.

Jerry had a set of rigorous standards for doing science. Lab activities, he believed, served as ways to practice a specific way of doing science by following specified procedures and answering questions about the lab. During interviews and observations, Jerry repeatedly emphasized a certain way of collecting, analyzing, and transforming data. Due to his rigorous standards for doing science, Jerry looked authoritative in the classroom; this created a unique classroom environment in which "students don't like to ask questions" (interview, 10/2). Therefore, Jerry's classroom was full of one-way talk in which he imposed the rules for doing science and even his meaning of fun on his students.

In his lab, Jerry only applied parts of his epistemological beliefs: science is proven to be valid through rigorous processes and validity depends on the context. He conceptualized that science was always valid in the school laboratory context, in which students were required to "re-discover" given scientific explanations. These epistemological beliefs were consistent with his primary goal and use of lab activities. In order to help students appreciate science, he used highly structured labs in which students directly experienced rigorous experiments and evaluated data based on a "given" theory. In so doing, Jerry believed, students better appreciate science. Students, however, never had a chance to evaluate a theory because school science was about "knowledge that already exists."

SUMMARY

Each teacher in this study has shown unique beliefs and actions. Pamela demonstrated naïve epistemological beliefs. She viewed science as factual information and never questioned the verity of scientific knowledge. Moreover, she considered herself and students as consumers of science and never attended to deeper cognitive processes involved in evaluations of data. These beliefs were consistent with her primary teaching goal, delivering information. This goal, in turn, seemed to lead Pamela to replace student lab activities with demonstrations that enabled her "to convince" the truth of the information and to ensure enough time for delivering information. In her case, her epistemological beliefs, goals, and actions are clearly connected (Figure 1A).

Tom demonstrated more complex connections among beliefs, goals, and actions. He showed a broader perspective on science by including processes of problem-solving as well as knowledge itself. His view of science as a body of factual knowledge was consistent with his goal of delivering information and his view of students as passive information

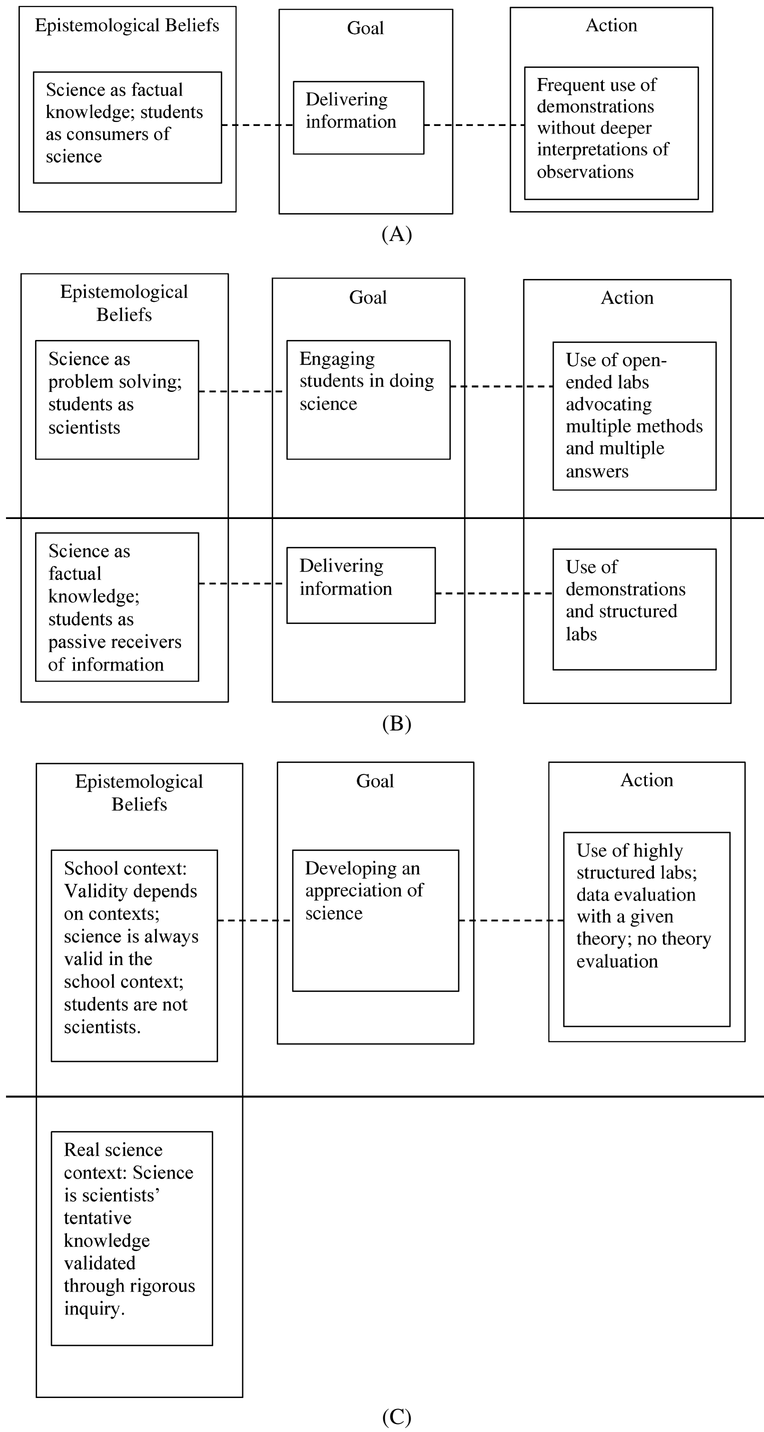

Figure 1. Connections among each teacher's epistemological belief, goal, and typical use of lab activities. (A) Pamela's naïve epistemological beliefs are consistent with her goal and way of using lab activities, (B) Tom applies two distinct epistemological belief sets to two different goals that are connected to two different ways of using lab activities respectively, and (C) Jerry separates the school context from the "real science" context and applies partial aspects of his epistemological beliefs to his instructional goal and use of lab activities.

receivers. He linked these beliefs to his use of demonstrations and structured lab activities. On the other hand, Tom occasionally emphasized science as a process of problem solving and provided students with open-ended activities advocating multiple methods and multiple answers. In so doing, he empowered his students as scientists and tried to engage students in doing science. Tom linked his two different epistemological belief sets with different goals and actions through his statements and ways of using lab activities as if he operates in two different worlds (Figure 1B).

Jerry demonstrated another level of complexity in the connections among beliefs and actions. He expressed contextualism in his epistemological belief statements. He believed in multiple truths that are valid depending on contexts. Given the context-dependent view of validity, Jerry perceived that science was always valid in "school laboratory contexts" and never provided opportunities for students to evaluate multiple theories. Instead, he aimed to help students appreciate science through direct experiences of rigorous scientific validation processes in which students evaluated data with a given theory. In so doing, his lab activities never reflected the tentative nature of science. Jerry explicitly expressed that his lab activities only addressed rigorous validation processes following privileged ways of doing and thinking. His lab provided students with partial aspects of the nature of science (Figure 1C).

DISCUSSION

Teachers conceptualize and implement the art of teaching by orchestrating multiple factors (Gess-Newsome & Lederman, 1994; Shoenfeld, 1998; Tobin, McRobbie, & Anderson, 1997). Among the various factors identified in the literature, the current study has shown that teachers' epistemological beliefs and instructional goals can partly explain teaching practices and use of lab activities in particular. Teachers who have naïve epistemological beliefs are likely to pursue delivering information as a primary instructional goal and use more demonstrations in a way of show-and-tell. This way of using lab activities is consistent with external teaching conditions such as preordained curriculum and external tests to the extent that the teaching practice is rarely challenged (Tobin, 1986; Tobin & McRobbie, 1996). These simple connections among teachers' epistemological beliefs, goals, and teaching practices, however, are not clearly shown when teachers have sophisticated epistemological beliefs. The cases of this study and others (Lederman, 1999; Tobin, McRobbie, & Anderson, 1997) demonstrate that teachers' sophisticated epistemological beliefs are rarely reflected in their teaching practices. The teachers may prefer meaningful teaching approaches (Hashweh, 1996), but actual classroom practices are also influenced by a variety of factors in schooling (Barnett & Hodson, 2001; Lederman, 1999; Tobin & McRobbie, 1996; Yerrick, Pedersen, & Arnason, 1998).

The findings of this study imply some possible explanations for why teachers teach the way they do particularly, in the cases of teachers with sophisticated epistemological beliefs. First, teachers negotiate differently in their commitment to their epistemological beliefs with their perceived teaching contexts. For example, in the case of preordained curriculum constraint, a certain teacher may, just like Tom, view science as both preordained and open-ended and manage to provide opportunities for students to emulate scientific inquiry while complying with the curriculum constraint during other times. In this case, the teacher seems to perceive the constraint as manageable and controllable to some extent. In contrast, a certain teacher may have very sophisticated epistemological beliefs about science but completely separates "real science" context from the science teaching context and does not fully apply the sophisticated view to teaching actions. Just as the teacher separates "science" from "school science," students are separated from science; science learning becomes talking about science rather than doing science. By separating science from school science, the teacher does not need to confront the teaching constraints that are conducive to structured verification labs. Instead, the teacher approves the teaching conditions as a given and never considers experimenting with alternative teaching practices. In this case, the teaching contexts seem to override a need for teaching science as inquiry.

Second, the teacher's instructional goals seem to be closely related to their ontological beliefs. The cases in our study demonstrate that a certain teacher, just like Pamela, tends to pursue the delivery of information when the teacher views science as accumulative factual knowledge that is a fixed entity. Hence, students' cognitive involvements are minimized. On the other hand, teachers may not emphasize only delivering factual information when they consider science as tentative and evolving knowledge. They tend to emphasize problem solving or reasoning involved in processing data and supporting claims. These varying emphases seem to result in differences in their practices.

Third, the relational aspect of teachers' epistemological beliefs seems to guide their design of instructional activities. When teachers separate students from science, they perceive students as passive learners who are "spectators" of science (Yerrick, Pedersen, & Arnason, 1998). In contrast, when a certain teacher connects science to students, the teacher views students as small scientists who are able to construct meanings on their own. The teacher, therefore, tends to provide students with opportunities for doing science to have ownership of their learning.

The findings of this study suggest that teachers' diverse teaching practices are relevant to their different synthesis of three components: ontological beliefs, relational aspects of epistemological beliefs, and instructional goals. When a certain teacher views science as definite true knowledge and separates students from science, the teacher may focus on transmitting knowledge. When a certain teacher views science as evolving knowledge and considers basic questioning and answering processes as science, the teacher may encourage students to do science just like scientists. When a certain teacher views science as tentative and evolving knowledge but does not relate science to students, the teacher may focus on talking about scientists' science describing science as inquiry, but students may not have opportunities to directly experience authentic scientific inquiry. The possibility that different combinations of ontological and relational aspects of epistemological beliefs produce various teaching practices supports the argument that epistemological beliefs are multidimensional (Hofer, 2000). In particular, ontological and relational aspects seem to be distinct dimensions of epistemological beliefs explaining different parts of teaching practices.

Teachers' various teaching practices also depend on their different perceptions of student needs that shape their primary goals. Although both Pamela and Tom were teaching physical science to low-achieving students, Pamela perceived scientific information as students' primary need whereas Tom believed that emotional support and engaging students in doing science are as much important as delivering information. In contrast, Jerry deemphasized delivering information. He, instead, focused on thinking processes involved in lab activities while privileging a certain way of doing and thinking science. To some extent, Jerry's deemphasis on delivering factual information may have originated from his sophisticated epistemological beliefs. However, had he taught lower grade students who had to take a graduation test or who were struggling to meet the standards, Jerry might have negotiated his emphasis on thinking processes with his students' needs for passing the graduation test. Further research with various cases will shed light on how teachers negotiate their commitment to their epistemological beliefs with instructional goals based on various student needs.

IMPLICATIONS

The current science reform promotes constructivist teaching approaches (AAAS, 1993; NRC, 1996; Millar & Osborne, 1998) and several studies demonstrate successful constructivist teaching practices on a high school level (Hammer, 1997; Roth & Roychoudhury, 1993; van Zee & Minstrell, 1997). Our study complements previous studies by providing pictures of how "regular" teachers employ or fail to employ constructivist teaching approaches in using lab activities. Obviously, for successful reform, providing teachers with opportunities to negotiate their epistemological beliefs with those of the reform position should be a starting point. The findings of our study, however, have shown that teachers' sophisticated epistemological beliefs are necessary but not sufficient. Teachers may have sophisticated views of science but do not always apply it to their teaching practices. Teachers' instructional goals and teaching contexts should be understood because they influence teachers' commitment to putting their epistemological beliefs into practice.

Our study supports the view of epistemological beliefs as a multidimensional construct. Therefore, teachers' development of sophisticated epistemological beliefs needs assistance in multiple directions including ontological and relational aspects. Moreover, these beliefs should be discussed in connection with instructional goals and teaching conditions. For these purposes, teachers' collaborative analysis of their own classroom teaching cases is found to be an effective method (Hammer & Schifter, 2001; Kang, 2004). Paper will be presented at the SITE (Society for Information Technology and Teacher Education) International Conference. Atlanta, GA). In this method, teachers either videotape or write about their classroom teaching episodes and reflect upon them with their colleagues. In this method, videotaped or written cases assist teachers in reflecting on their own teaching practices as objects of thought. Moreover, teachers' own teaching cases provide opportunities to discuss epistemological beliefs and instructional goals in reference to their specific teaching contexts. For general use of this method, it is necessary to develop a tool that can guide teachers' analyses of their own teaching actions and support constructive criticism during the collaborative reflection. Examples of the analysis of classroom teaching practices in alignment with the current reform documents may be an effective tool. In developing the examples, our findings imply that explicit connections among the nature of science, instructional goals, and teaching practices are essential. Otherwise, teachers may develop sophisticated epistemological beliefs while they are committed to traditional pedagogical approaches.

This study has limitations including limited sampling, self-selected data, and lack of data from students. Further research should involve cases from different teaching contexts such as urban school settings and students' perceptions of teachers' goals and teaching actions. The information on student perceptions, in particular, will help teachers evaluate their teaching actions based on students' perspectives.

This study has led us to more questions about teachers' developments of epistemological beliefs and instructional goals. Further research needs to answer questions such as (a) What made some teachers develop sophisticated epistemological beliefs while others do not? and (b) Why do some teachers perceive student needs differently to the extent that they set up different primary instructional goals that guide their teaching practices? We need more studies about the process of teachers' perception of student needs and teaching goals in relation to their epistemological beliefs. Several studies reported beginning teachers' epistemological beliefs and actions (Bryan & Abell, 1999; Munby, Cunningham, & Lock, 2000; Schoenfeld, 1998; Tobin, McRobbie, & Anderson, 1997). Comparisons between beginning and expert teachers and longitudinal studies of teachers' development will provide a deeper understanding of teacher development.

APPENDIX A

Initial Interview Guide

1. What do you mean by laboratory activities or hands-on activities?
2. How often do you use hands-on activities when you are teaching?
3. What types of hands-on activities do you use?
4. What roles do you believe lab activities play in your teaching?
5. I would like you to read the following incidents and explain how you would respond to each incident.

   Incident #1. A class of ninth grade are heating magnesium ribbon in a crucible with a lid. The purpose of the lesson is to test the consequence of oxygen theory that materials gain weight when burnt. At the end of the lesson, 4 groups report a loss in weight, 2 groups report no difference, and 2 groups report a gain in weight.

   Incident #2. Seventh grade students are doing experiments with circuit boards. With two bulbs in series, many find that one is lit brightly while the other appears to be unlit.

APPENDIX B

Final Interview Guide

1. What are the goals of teaching physics/physical science?
2. What makes you decide to use lab activities?
3. You used sometimes demonstrations and other times student lab activities. What are the criteria for choosing the types of activities?
4. What is your role in lab?
5. What are students' roles in lab?
6. Would you compare the way scientists work with the way students learn in science?

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