

# Investigating pre-service elementary teachers' epistemologies when talking about science, enacting science and reflecting on their enactment

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**Abstract:** We described and compared 94 pre-service elementary teachers' epistemologies during three different activities: one semi-structured interview, an asynchronous on-line discussion about a physics problem and their reflection on the discussion of the second activity. Using discourse-based analysis, we analyzed the data in terms of the teachers' underlying epistemologies and findings revealed significant differences across the three activities. This suggests that (a) teachers' epistemologies might be better understood as finer grained cognitive resources whose activation is sensitive to the context, unlike most research which views them as coherent and stable cognitive structures, and that (b) the research community is far from settling the debate as to what particular approaches should be used to assess or study personal epistemologies. Depending on the context and the manner of investigation, students and teachers may "show" different epistemological understanding.

## Introduction

Current science education standards (NRC, 1996; 2007) argue that inquiry should be a central strategy of science instruction, partly because that inquiry can be a dynamic way for helping students to develop sophisticated understanding of the nature of science (NOS) or sophisticated scientific epistemologies. Epistemology is a term used differently by philosophers and psychologists (Sandoval, 2005). For the purposes of this paper we take scientific epistemologies to mean the individual's understanding of or views about the nature and characteristics of scientific knowledge and its construction, including the sources of scientific knowledge, its truth value and what constitutes scientifically appropriate warrants, and science as a way of knowing and its values inherited in the development of the scientific knowledge (Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick et al., 1998; Lederman, 1992). The development of sophisticated epistemologies has been a central component of scientific literacy for some years (AAAS, 1993; NRC, 1996).

However, this agenda has been slow to become established in instructional practice for a number of reasons. First, despite a wide consensus for the importance of developing epistemological awareness in science among learners, the education community has yet to agree on precisely how this awareness is developed, how epistemological knowledge is developed and in what form (Louca et al, 2004). Most research on personal epistemologies has assumed they consist of developmental stages or beliefs and thus can be explicitly taught and developed (van Driel et al., 2001; Olson, 2007). Others have advocated a structure of epistemologies that consists of units of cognitive structure at a finer grain size than stages or beliefs, suggesting that it is not really a matter of developing new knowledge constructs, but a matter of organizing a network of existing epistemological resources (Louca et al, 2004; Hammer & Elby, 2002). Second, there is no consensus regarding the methodological approaches used to study students' epistemologies (Sandoval, 2005). One approach has argued that students' epistemologies can be directly investigated, e.g., via interviews (Van Driel et al., 2001). A second approach has suggested that students' personal epistemologies are manifested through practice, and, thus, practice is the only way of studying them (Sandoval, 2005; Richardson, 1996). These ambiguities have resulted in a rather fragmented picture of students' epistemologies, with often contradicting findings and frequently students' practices of inquiry appear to share much with scientific practice but their expressed epistemologies are naïve (Sandoval, 2005).

Our purpose in this paper was to investigate 94 pre-service elementary teachers' epistemologies while engaged in three different activities. The differences among these activities refer to the context in which we investigated their expressed or enacted epistemologies. Firstly, participants were prompted to talk about their personal epistemologies during an individual interview. Secondly, they were asked to "enact" science, by talking about a physics topic on relative motion through an online discussion (without specifically talking about their personal epistemologies). By enactment, we refer to the participants' efforts to reach a consensus about a problem related to relative motion. In some cases this involved students trying out experiments and reporting them to the group or debating various points of view. Thirdly, they were asked to reflect on their enactment of

science during the second activity by debating whether their discussion was scientific or not – thus, prompting them to reflect on the NOS underlying their discussion of relative motion.

## Theoretical framework

### Current views of NOS

Traditionally, science has been presented to students as a rigid body of facts, theories, and rules to be memorized and practiced, rather than a way of knowing about natural phenomena (van Driel et al., 2001). The learning of correct answers, memorizing of information, rote learning, and reading were central components of the exploration of questions, critical thought, understanding in context, argument, and doing science. In this view, teaching science assumed that an already developed body of knowledge, one generally accepted by the scientific community, could be transmitted to students through passive instructional means (Tobin, Tippins, & Gallard, 1994).

To an increasing extent this approach has become the subject of criticism among policy makers, teachers, educators, and researchers (e.g., Tobin et al., 1994). This approach has been related to the decreasing popularity of science among students (van Driel et al., 2001). Furthermore, research on students' scientific epistemologies has demonstrated that students exposed to this approach often end up with a poor understanding of scientific concepts (van Driel et al., 2001). Moreover, science education in its traditional form fails to adequately prepare future citizens to understand science and technology issues in a rapidly evolving society (Millar & Osborne, 1998).

Recently, modern views of NOS suggest that scientific knowledge is (a) tentative (that is, subject to change), (b) empirically based (that is, testable), (c) subjective (and thus, not absolute), (d) creative, (e) socially and culturally embedded, (f) unified, (g) amoral, (h) parsimonious (scientific knowledge attempts to achieve a simplicity of explanation as opposed to complexity), and (i) differentiates between observation and inference (Abd-El-Khalick, Bell, & Lederman, 1998). In this sense, scientific knowledge is based on observations from the natural world and reflects human attempts to impose order on the understanding of nature and explain the mechanism underlying the physical phenomena.

Reform documents (e.g., AAAS, 1990; NRC, 1996) and researchers (e.g., Lederman, 1992; McComas & Olson, 1998) have advocated that there are several elements of NOS that should be communicated to students in order for them to become scientifically literate. Thus, aspects of NOS are crucial to guide the current assessment of individuals' understandings of NOS, because they are not contentious, they are developmentally appropriate for K–12 students, they are learnable by K–12 students as indicated by empirical research, and they are arguably important for all high school graduates to know. Consequently, the objective of helping students (and teachers for that manner) to develop understandings of NOS is one of the most common objectives for science education (Abd-El-Khalick, Bell, & Lederman, 1998).

### Views about the nature of scientific epistemologies

Disagreements about the tenets of NOS exist at a general level among scientists, science educators, historians and philosophers of science. Despite these disagreements, there is a widely shared view which suggests that individuals' epistemologies have a developmental aspect and that these are learnable throughout K–12 (Abd-El-Khalick & Lederman, 2000). This perspective presents the development of epistemologies as developmental stages somewhat resembling cognitive development as conceptualized e.g., by Piaget (1967). For instance, in the seven-stage scheme of King and Kitchener (1994), children initially view knowledge as comparatively certain and gained from authority or direct observation. From there they progress to relativist stages in which they view knowledge as constructed and different viewpoints as valid. Finally, some reach expert stages in which they see knowledge as constructed yet subject to scrutiny, judgment, and synthesis. Invoking more recent developmental theorists such as Fischer's (1980), King and Kitchener (2004) adopt a "complex stage theory" in which a typical subject's epistemology is like a wave spread over two stages.

A second perspective suggests that students' epistemologies are not a unified whole. Following a growing set of studies that suggest that students' epistemological views of science are not stable coherent frameworks, but inconsistent, fragmented and possibly unstable beliefs, this perspective deals separately with each different dimension of NOS, such as, structure, certainty and source of knowledge (Hofer & Pintrich, 1997). It suggests that learners' epistemologies along each dimension are assumed to consist of semi-independent beliefs, implying that a student could hold sophisticated views about the structure of e.g., physics knowledge, seeing it as a hierarchy of concepts rather than a collection of equations, while also holding naïve beliefs about the certainty of that knowledge, viewing new theories as fixed and absolute. In Leach et al.'s (2000) study, students' responses to decontextualized and contextualized open-ended survey items that asked them to reason about the relation between theory and data were found to be inconsistent across the two contexts. Sandoval and Morrison (2003) interviewed a sample of high school students before and after a month-long intervention and found that both individual students' responses to different questions reflected different

epistemological levels, and that student responses were not stable across interviews (nor predictable). According to this perspective, views about NOS consist largely of comparatively stable, robust cognitive structures corresponding to articulate, declarative knowledge. These epistemologies are taken to be the units of views about NOS (Schommer-Aikins, 2004). Some researchers view epistemological beliefs as comparatively global (Schommer, 1990), while others have investigated how epistemological beliefs vary by discipline, e.g., in chemistry vs. psychology (Hofer, 2002a). What they all agree upon, however, is that epistemologies consist largely of comparatively stable, robust cognitive structures corresponding to articulate, declarative knowledge.

Hammer and colleagues (Hammer & Elby, 2002; Louca et al., 2004) have proposed a third perspective, suggesting that personal epistemologies are made up units of cognitive structure at a finer grain size than stages or beliefs, which they call resources. Rather than attribute to individuals any general epistemological theories or beliefs, they understand them to have a range of cognitive resources for understanding scientific knowledge and its nature. They suggest that the difference between naïve and expert epistemologies lies not just in the content (views), but also in the form of the relevant cognitive elements. Other studies show that students often hold inconsistent epistemologies which emerge in different contexts (Hammer, 1994; Roth & Roychoudhury, 1994; Solomon, Duveen, & Scott, 1994). There is also some evidence for fragmented epistemologies from those studies that have been unable to assign large portions of students to a single epistemological “type” (Khishfe & Abd-El-Khalick, 2002; Linn & Songer, 1993). In this sense, a teacher’s professed epistemology, for example, her stated views about knowledge and learning, may possibly differ substantially from her enacted epistemology, the views about knowledge and learning an observer would infer from her classroom behavior (Hofer, 2002b; Tobin & McRobbie, 1997), suggesting that it could be a matter of different resources being activated in different contexts – that of an interview and of teaching contexts (e.g., Louca et al., 2004; Leach et al., 2000; Roth & Roychoudhury, 1994; diSessa, Elby, & Hammer, 2002).

### **Novice teachers’ epistemologies**

A large number of studies have indicated that teachers’ epistemologies influence their teaching and their students’ learning to a great extent (AAAS, 1993; NRC, 1996). As a result, researchers have investigated teachers’ epistemologies, in addition to developing programs that seek to improve them (e.g., Abell & Smith, 1994; Palmquist & Finley, 1997; Abell et al., 2001). Many of these studies were consistent in showing that teachers (both in-service and pre-service) possessed naïve scientific epistemologies (e.g., Abd-El-Khalick & BouJaoude, 1997).

Moreover a number of these studies has provided insights about how novice teachers (pre-service and early-career teachers) encounter teaching and their ability to reflect on practical experience (Penso, Shoman, & Shiloah, 2001), how science teachers’ views about science and science teaching influence their classroom practice (Brickhouse & Bodner, 1992) and how induction programs are essential in addressing the pedagogical and content needs of science teachers (Luft, Roehrig, & Patterson, 2003). Other studies have documented the nature and persistence of pre-service teachers’ epistemologies. For instance, many pre-service teachers think of teaching as passing on knowledge, and learning as absorbing and memorizing knowledge (e.g., Calderhead & Robson, 1991). When they imagine themselves teaching, pre-service teachers often picture themselves standing in front of a group of attentive students presenting information, going over problems and giving explanations. A significant proportion of teachers believe that scientific knowledge is not tentative, and hold a positivistic, idealistic view of science (Lederman, 1992).

### **The relationship between teachers’ views of NOS and classroom practice**

Research concerning improving teachers’ epistemologies has followed the assumption that teachers’ epistemologies directly transfer into their classroom practices (Lederman, 1992). In other words, it is assumed that studying teacher practices can help understand their epistemologies (Sandoval, 2005), and that improving teachers’ epistemologies is sufficient for promoting “effective” NOS instruction in science (Lederman, 1992).

However, through a range of studies, it is currently understood that the relationship between teachers’ epistemologies and their classroom practice is more complex than originally assumed. Several factors have been identified to mediate and constrain the translation of teachers’ epistemologies into practice. These factors include pressure to cover content (Abd-El-Khalick et al., 1988; Hodson 1993), classroom management and organizational principles (Hodson, 1993), concerns for student abilities and motivation (Brickhouse & Bodner 1992; Lederman, 1999), institutional constraints (Brickhouse & Bodner, 1992), teaching experience (Lederman, 1999), discomfort with understandings of NOS, and the lack of resources and experiences for assessing student epistemologies (Abd-El-Khalick et al., 1998).

Research on the translation of teachers’ epistemologies into classroom practice indicates that even though these can be thought of as a necessary condition for promoting the development of students’ NOS understanding, these epistemologies should not be considered sufficient (Lederman 1992). This may suggest that research efforts should concentrate beyond simply identifying teachers’ professed epistemologies, to investigating their translation into enacting (or practical) epistemologies as they appear during everyday

teaching. By teachers' practical epistemology we refer to the set of epistemologies about one's own knowledge production in school science, including what knowledge is, the methods through which knowledge can be produced, and the criteria for evaluating knowledge claims, which are reflected in the epistemic decisions people make during the construction and evaluation of scientific knowledge (Sandoval, 2005).

All these issues raise three questions about teachers' scientific epistemologies and their development. First, the nature of epistemologies remains somewhat unclear; whether epistemologies are organized in coherent frameworks, or are fragmented beliefs or finer-grain resources. Second, the specific epistemologies that guide teachers' practices are largely unknown. Third, the relation of these practical epistemologies and teachers' expressed epistemologies are not well articulated. Given the discrepancy between what teachers seem able to do and the difficulty they have in articulating epistemological aspects of formal science, it seems more likely that epistemological beliefs are contextualized rather than coherent frameworks (Hammer & Elby, 2002).

Our purpose in this paper is to contribute specifically to these needs: to investigate teachers' expressed and practical epistemologies through multiple data sources. The differences among these data sources refer to the context in which we investigated their expressed or enacted epistemologies. Thus, we compare 94 pre-service teachers' expressed epistemologies as revealed through an interview, their practical epistemologies underlying a discussion about relative motion, and their epistemologies underlying a reflective discussion about whether their science enactment in the relative motion discussion was scientific or not.

## Methodology

The present study was interpretive in nature and focused on the epistemologies that participants held, expressed or underlay their actions in the three aforementioned tasks. Ninety-four pre-service elementary teachers participated in this study. All participants were enrolled in a science methods course in the same semester (separated in two groups), taught by the first author. The data collection took place at the very beginning of the course (during the first three weeks), prior to any intervention and discussion about NOS characteristics.

Data sources consisted of three different activities. For the first activity we randomly selected 47 out of the 94 pre-service teachers of the study, whom we interviewed individually about their views concerning NOS. All interviews were conducted by the second author, using a semi-structured protocol which focused on three areas, namely, demographics, views about science and about teaching science. The first part of the interview focused on identifying pre-service teachers' experiences with science from both pre-university and university studies. The second part of the interview aimed at identifying pre-service teachers' epistemologies (for instance, we asked them what is Science for them; under what conditions is something scientific; and what does the term "experiment" mean to them). The third part of the interview focused on investigating pre-service teachers' views about science teaching. For instance, we asked them what they thought the goal of Science education is; about the role of a teacher during a science lesson; and what they thought the components of a "good" science lesson are. Finally, interviewees watched a short video clip from a science lesson and were asked to comment about the ways they might respond to students' ideas and reasoning, had they been the teacher during this lesson.

For the second activity, all 94 teachers had an online, asynchronous threaded discussion about relative motion. We randomly assigned pre-service teachers into groups of 10 or 11 participants and provided them with a question on relative motion: A person is running, holding a set of keys in her hand, which she holds still next to her body. What would happen to the keys, if she let go, while still running? We asked each pre-service teacher to have at least one posting of her own answer to the question, respond to at least three other group-mates' answers, respond to all the comments she received for her own postings, including her answer to the initial question, in an effort to reach consensus about the answer to the question, after discussing this with the rest of the members of her group. The pre-service teachers had a week in which to reach a consensus. A total of 341 posts were made by the 94 teachers which reflected an average of 80 words per post, and all groups of students were close to, or reached consensus. The third activity was also an online, asynchronous threaded discussion, carried out by the same groups of pre-service teachers as above. This occurred immediately after the second activity and also lasted for a week. In this activity, pre-service teachers had to reflect on the discussions they had during the second activity, in an attempt to discover whether that discussion was scientific or not. A total of 359 posts were made by the 94 teachers, which reflected an average of 105 words per post.

All interviews were transcribed and along with all threaded discussions served as the primary sources of data. We analyzed all data using a discourse-based analysis focusing on three particular aspects of NOS: (a) what is science (b) what is the result of science and (c) what is scientific knowledge? Categories for this analysis were drawn from the literature we have described in the theoretical framework of the paper. Some categories identified in the literature were not observed in our data and thus are not part of our coding scheme. The final categories that we used for each aspect of NOS were organized in an ordinal scale based on their sophistication. Each teacher's postings for a particular discussion were analyzed separately and coded in terms of the underlying ideas about the three aspects of NOS. The same was done with each participant's interview. In all cases, each teacher's postings or interview was assigned with only one code for each of the three aspects of the

NOS. All codings were carried out independently by the first and the second author (Cohen's Kappa=0,84), and differences were resolved through discussion.

We used descriptive statistics to compare teachers' views about the result of science, science as a process and the scientific knowledge from the three different contexts. Lastly, the non-parametric Wilcoxon Signed-Rank Test was applied to test for significant differences in teachers' views among the three data sources (contexts). The test was applied only to the 47 pre-service teachers from whom we had data from all three contexts.

## Findings

Findings revealed considerable differences among teachers' epistemologies about NOS in the three contexts (see Table 1). Activity 1 will be referred to as "interview," activity 2 as "enacting science" and activity 3 as "reflection."

Table 1. Differences between teachers' epistemologies about NOS

Codes	Interviews	Enactment	Reflection
<i>A. Science</i>			
<i>i. The result of science:</i>			
1. improves life quality	14.3%	0.4%	0%
2. is a number of laws that govern the physical world	5.7%	83.9%	8.6%
3. provides answers to questions about physical phenomena	20.0%	0%	0.8%
4. is an interpretation of everyday physical phenomena	60.0%	15.7%	90.6%
<i>ii. Science (as a process) is:</i>			
1. a process of memorizing scientific facts	0%	0%	0%
2. a process of observations and experimentation	45.7%	17.6%	43.2%
3. a process of investigating, accepting or rejecting theories or hypotheses	54.3%	82.4%	56.8%
<i>B. Scientific knowledge is:</i>			
1. absolutely true (there is only one answer)	20.0%	5.3%	10.5%
2. how each individual understands the truth about the physical world	5.7%	77.5%	33.7%
3. the most commonly accepted answer to questions about the physical world	5.7%	9.0%	47.1%
4. the knowledge we learn from experimentation	54.3%	4.1%	6.2%
5. a truth that might change in the future	14.3%	4.1%	2.5%

### Pre-service teachers' epistemologies related to what is science

When "enacting science" most of the pre-service teachers (83.9%) felt that the result of science consists of a number of laws that govern the physical world. This idea appeared less often in the interviews (5.7%) and in the reflections (8.6%). During the interviews, pre-service teachers suggested that science improves quality of life (14.3%) and provides answers to questions about physical phenomena (20.0%); these ideas did not appear during the two online discussions. During the interview and the reflection, the majority of the teachers felt that scientific knowledge is an interpretation of everyday physical phenomena (60% and 90.6%, respectively), an idea which did not appear as often when teachers enacted science (15.7%).

### Pre-service teachers' epistemologies related to what is the result of science

During the interviews, pre-service teachers described science as a process of observation and experimentation (45.7%). Similarly, this idea appeared in teachers' reflections (43.2%), while only 17.6% of the pre-service teachers seemed to use this idea while enacting science. When enacting science, most of the pre-service teachers (82.4%) seemed to view science as the process of investigating, accepting or rejecting theories. However, during their reflection and the interview, only about half of the pre-service teachers (56.8% and 54.3%, respectively) seemed to view science as such. The other half (43.2% and 45.7%, respectively) viewed science as a process of observation and experimentation. None of the teachers appeared to see science as a process of memorizing scientific facts during the three activities.

### Pre-service teachers' epistemologies related to what is scientific knowledge

While enacting science 77.5% of the pre-service teachers felt that scientific knowledge reflects how each individual understands the truth about the physical world, whereas, during the reflection fewer teachers (47.1%)

seemed to understand scientific knowledge as the most commonly accepted answers to questions about the physical world. During the interview more than half of the teachers (54.3%) indicated that scientific knowledge is what we learn from doing experiments. This idea appeared less during the rest of the activities. Moreover, during the interview 20.0% of the teachers seemed to understand scientific knowledge as absolutely true, but less seemed to do so during their reflections (10.5%) and even less when they enacted science (5.3%). Similarly, during their interviews 14.3% of the pre-service teachers described scientific knowledge as a “truth” that might change in the future, an idea observed much less during the enactment of science (4.1%) and the reflection (2.5%).

### Comparison of pre-service teachers epistemologies across the three contexts

Overall, the Wilcoxon Signed-Rank Test indicated that the pre-service teachers’ epistemologies for each of the three aspects of NOS investigated were statistically significantly different across the three contexts. Specifically, the pre-service teachers’ epistemologies about the result of science differed significantly among all three contexts ( $p < 0.001$  across all comparisons). In terms of what science is, pre-service teachers’ epistemologies during the interview and the reflection were not found to differ significantly, but both were found to differ significantly from the enacting science activity ( $p < 0.001$  across all comparisons). Finally, the findings concerning what scientific knowledge is, revealed that all the contexts were significantly different ( $p < 0.001$  across all comparisons).

### Discussion

The aim of this study was to investigate and describe pre-service teachers’ epistemologies from three different data sources reflecting three different contexts. Findings revealed statistically significant differences of the pre-service teachers’ epistemologies among the three contexts investigated, which raises two issues.

The first issue is related with the nature and/or the development of epistemological understanding. Our findings, along with a number of other studies (Hammer, 1994; Roth & Roychoudhury, 1994; Solomon, Duveen, & Scott, 1994; Hammer & Elby, 2002; Louca et al, 2004) contend that personal epistemologies seem to be better understood as fine-grain cognitive structures that are activated depending on the context in which the activation takes place. Asking teachers about their views of NOS or inferring those views from their enactment in science or their reflections seem to invoke statistically different epistemological resources, which they use to explain, understand or respond to a particular situation.

The fact that the differences among the three contexts are not similar in terms of the three areas of NOS that we have investigated (what is science, what is the result of science and what is scientific knowledge), has another important implication. It suggests that viewing personal epistemologies as semi-independent beliefs (Hofer & Pintrich, 1997; Schommer-Aikins, 2004) cannot explain these differences. The teachers’ epistemologies investigated in this study, differ among the three contexts, but the differences in the three areas of NOS investigated are not similar among the three contexts. Teachers’ epistemologies are not only different across contexts, but there is also a variation of those differences within the various contexts. For instance, pre-service teachers’ views about science as a process are similar between the interview and the reflection. However, the same teachers’ views about the nature of scientific knowledge are statistically significantly different in the two contexts. Thus, we suggest that our findings indicate that even within a particular area of NOS, the same pre-service teachers hold multiple epistemological resources, which they activate based on context. Thus, attributing robust epistemologies developed into coherent theories (McComas, 1996; Sandoval & Morrison, 2003) to pre-service elementary teachers is definitely inappropriate.

The second issue is related to the debate that exists in literature about the approaches of studying personal epistemologies (Sandoval, 2005). Assessments of formal science tend to ask students to express their views about the nature of scientific knowledge and activity, including questions about what scientists do, what theories are, how theories and experimentation influence each other and so forth. The general picture from such studies is that students’ ideas about formal science follow a developmental trajectory toward increasing sophistication throughout adolescence (e.g., Leach et al., 1997), but tend to remain fairly naïve even during university instruction. Our findings show a similar picture, which we feel suggests that the research community is far from settling the debate as to which particular approaches should be used to assess or study personal epistemologies. Depending on the context and the manner of investigation, students and teachers may “show” different epistemological understanding. One suggestion is that, the research community may choose to follow a multiple-data-source approach when studying personal epistemologies.

Finally, disagreeing with the suggestion that it is an academic issue whether teachers’ epistemologies are necessarily reflected in their classroom practice (Lederman, 1999), an implication stemming from our findings is that methodological effects might be possible. The ideas teachers express, explicitly or implicitly, may differ depending on the situation in which they are engaged. For example in the context of an interview, teachers may report views they believe they hold, whereas when they enact science, or reflect back on their enactment they may reveal “alternative” views. In the interview context, the teachers self-report views they

think they hold about an issue, which are often influenced by social desirability. While enacting science their conceptions will be interpreted by independent coders and are possibly influenced, not only by what they have been taught about science, but also by their experience with science in formal informal learning contexts. Consequently, we propose that a broader account of personal epistemologies should include investigations with methods that are not limited to questionnaire surveys and interviewing.

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