Learning the 'Grammar of Science': The Influence of a Physical Science Content Course on K-8 Teachers' Understanding of the Nature of Science and Inquiry

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The “nature of science” (NOS) typically refers to understanding science as a way of knowing or the values and assumptions inherent in the construction of scientific knowledge (Lederman, 1992). Science education in the U.S. has emphasized understanding NOS most recently as a critical component of scientific literacy within national reform documents including *Science for All Americans* (AAAS, 1990), *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996). Despite these emphases, however, Lederman’s (1992) review of the research and studies since (e.g., Akerson, Abd-El-Khalick & Lederman, 2000; Bianchini & Colburn, 2000; Schwartz & Lederman, 2002) reveal that teachers generally do not possess informed views of NOS and inquiry. This study examined efforts to improve practicing K-8 teachers’ understandings of NOS in the context of a science content course.

Efforts to Improve Teachers’ Understandings of NOS

In order to achieve the goal of scientific literacy outlined in the reforms, teachers must first understand NOS themselves. As such, science educators have undertaken efforts to improve teachers’ understandings of NOS aspects advanced by the reforms through professional development workshops and institutes (e.g. Akerson & Hanuscin, 2003; Lederman, Schwartz, Khishfe, Lederman, Matthews, & Liu, 2002), inquiry immersion or research experiences for teachers (e.g. Schwartz & Crawford, 2003), courses in science education designed specifically to teach NOS (Schwartz & Lederman, 2002), and science methods courses (e.g., Bianchini and Colburn, 2000; Gess-Newsome, 2002). However, many such efforts have met with only limited success in helping teachers develop and retain views of NOS consistent with current reforms (e.g., Abd-El-Khalick, Bell, & Lederman, 1998; Akerson, Morrison, & Roth-McDuffie, 2003).

Abd-El-Khalick & Lederman (2000) proposed that efforts undertaken within teacher education programs to enhance teachers' conceptions of NOS can be further enhanced by relevant coursework in other academic departments and programs, such as history of science or science content courses. McComas, Clough, and Almazroa (1998) suggested that learning the nature of science in this context legitimizes it as a useful domain for learners. Given the proliferation of specialized science content courses for teachers (Crowther, n.d.), there exists a unique opportunity to improve teachers' views in regard to aspects of NOS they will be expected to teach. However, few studies have examined the potential of such courses to promote accurate NOS understandings, and little is known about the ways in which faculty address NOS in their courses. In the only such study known by this researcher, Abd-El-Khalick (2001) investigated NOS taught within a physical science content course for preservice elementary teachers. Given the course was offered by the Department of Education and taught by a science educator, however, the findings do little to inform us of the potential of those courses offered by science departments and taught by science faculty to foster appropriate conceptions of NOS.

Purpose of the Study

The purpose of this study was to examine the empirical basis for recommendations for NOS instruction in content courses. The context was a physical science content course for teachers offered by the Department of Physics as a large university in the Pacific Northwest. Practicing teachers from around the nation enroll in the course as a 6-week intensive summer institute, equivalent in both classroom contact time and credit hours to three regular-term courses. Participants complete laboratory-based investigations into topics including magnetism, properties of matter, simple machines, and light & color. Work is conducted in pairs, and is self-paced by the learners. Program instructors regularly meet with participants to conduct formative assessments at predetermined points throughout the curriculum, checking their progress through each of the laboratory exercises. The pedagogical model can be described as "guided inquiry", since participants are given a question and materials, but may be asked to design investigative procedures and collect and interpret data (Colburn, 2000).

Because understanding NOS was identified as an "intellectual objective" of the course by its developers, this setting was well-suited for investigation into ways that science faculty define and integrate NOS into their curriculum, as well as the development of teachers' views of NOS. A total of 9 instructional staff and 27 classroom teachers (grades K-8) participated in the study. The research questions, which were refined throughout the data collection, included:

1. What are teacher participants' views of the nature of science prior to their participation in the course? How do these compare to views expressed in science education reform documents?
2. How, if at all, do teacher participants' views change over the course of the Physics by Inquiry summer institute?
3. What factors contribute to these changes, or lack of change?
    - What are the goals of the program? How do these relate to the nature of science? How are these goals articulated by the staff and administration of the summer institute?
    - What views of the nature of science are expressed in the published curricula? In what ways are these communicated?
    - What views of the nature of science are held by the program facilitators? How, if at all, are these views expressed in their instruction of the curricula?
    - What learning occurs outside of the formal curriculum? In what ways is this learning communicated to participants and by whom? What is the significance of these learnings to the nature of science?

Theoretical Underpinnings

The research took a naturalistic and interpretive stance, utilizing a combination of observation, interview, and document analysis to develop an understanding of the development of teachers' views of the nature of science (Bogdan & Biklen, 1998; Tobin, 2000). Moschkovich and Brenner (2000) emphasize that naturalistic inquiry recognizes that learners continually negotiate the content and meaning of science within multiple communities, and thus is appropriate for studying cognitive activity (such as learning about the nature of science) in context. This particular study was conducted under the assumption that teachers' views of NOS science are inextricably linked to the context in which they *do* and *learn about* science, consistent with theories of situated cognition (Brown, Collins, & Duguid, 1989).

Within the research, understandings of NOS were viewed as a cognitive, rather than affective outcome of learning (Abd-El-Khalick & Lederman, 2000). For the purposes of this study, NOS was operationalized in terms of the aforementioned reforms, to include those aspects believed relevant and accessible to K-12 students and teachers (Lederman, et al., 2002). Specifically, the study examined the empirical, subjective, creative, socio-culturally embedded, and tentative NOS, as well as the lack of a universal recipe-like "scientific method" and reliance on both observation and inference. These were selected for focus because teachers are expected to help their own students understand these aspects of NOS. Such a pragmatic view, however, did not preclude consideration of other ways of operationalizing NOS, given the perspectives of scientists may differ from that of science educators (Pomeroy, 1993).

While much of the research on the development of teachers' views of NOS has focused on investigation into and characterization of NOS instruction as being either *implicit* or *explicit* in nature (Abd-El-Khalick & Lederman, 2000a), the present study recognizes that, in addition to what is explicitly taught, there are learning outcomes or "covert learnings" (Carspecken, 1996; McDermott, 1990) that may not be part of the formal curriculum. Vallance (1980) suggested that the concept of the "hidden curriculum" can provide the researcher with a framework to explore

(1) the kinds of learning provided by the program outside the formal curriculum; (2) the ways in which this learning is communicated to students and by whom; and (3) the significance of these covert learnings. More broadly, and rather than focusing solely on *instructional methods*, the researcher approached the study with the intent of identifying the learning that occurred within the formal curriculum and beyond it, that is, to more deeply understand the context of the program itself and the participants' experiences within it.

Sources of Data

The researcher served as a participant observer throughout the term, attending all class sessions (136 hours) and instructional planning meetings (7) in order to gain an understanding of the perspectives of both teacher and staff participants. Data collection proceeded with the research questions in mind, so that the researcher could identify holes or missing data chunks, determine whether the focus of the research was providing sufficient evidence to answer these questions, and whether the questions needed to be revised or data collection redirected.

Observational data took the form of field notes, collected both during class sessions and outside of class during lunch, breaks, and other informal gatherings of teacher participants. Additionally, staff meetings and instructional planning sessions provided data on the instructional strategies and intentions of the program staff. Because it was impossible for the researcher to capture all interactions of the participants and facilitators during each class session, data collection was enhanced by the use of audio taping. Facilitators volunteered to wear a clip-on microphone and microcassette recorder during class sessions, so that dialogue between teachers and facilitators might be captured.

Consistent with the qualitative nature and interpretive stance of the study, an open-ended instrument was selected to elucidate, describe, and characterize participants' views of NOS. The

VNOS-C (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) was used to assess teachers' views prior to and upon completion of the course, as well as the views of the staff participants. Following the recommendations of Lederman & O'Malley (1990), the VNOS-C was used in conjunction with interviews for validity purposes. Given their reflective nature, the interviews have a potential to serve as a treatment, and thus might confound results in a pre- post- study of teachers' views. As such, teacher participants were purposefully assigned to one of three groups: (pre-interviewees, post-interviewees, and non-interviewees) so that each was representative of the whole in terms of grade level and years of enrollment in the summer institute.

Interviews, lasting from one to two hours in length, were conducted with each of the nine program staff to clarify their instructional intentions and their beliefs about the teaching and learning of science. Finally, relevant documents (curriculum materials, instructors' manuals, handouts, etc.) were collected for analysis. These data sources provided additional insight into the instructional processes at work in the summer institute, as well as the intended curriculum.

Analysis

Ongoing analysis of field notes was conducted during data collection, and served to refine the research questions and guide further data collection. Formal analysis of data, conducted at the conclusion of data collection, consisted of several rounds of open-coding, categorizing, and refinement of categories to identify major themes within the findings.

Particular words, phrases, behaviors, ways of thinking, and events that repeated and stood out within the data formed the initial or "raw" codes (Carspecken, 1996). Codes were then organized into categories to illuminate processes and phenomena that were not readily apparent through descriptions of specific instances. The researcher then proceeded to connect data within categories by constructing taxonomies and developing generalizations and propositions from the empirical data (Taylor & Bogdan, 1984).

VNOS-C data was analyzed separately, and at the conclusion of analysis of other data sources to avoid bias or "seeing" participants' views of NOS manifest in their teaching and learning of the content. Following the recommendations of the developers of the instrument (Lederman, et al., 2002) follow-up interviews were analyzed separately from questionnaires and analyses were compared to validate the findings. The analysis of VNOS-C data centered on characterizing respondents' views of NOS and the degree to which views of the participants are aligned with science education reforms (AAAS, 1990, 1993; NRC, 1996). Profiles of each were generated from pre- and post- data to identify changes in individual participants' views over the course of the term. Patterns of change across participants were identified, with care being taken to detect any treatment effects due to interviews.

In the final round of analysis, themes were cross-checked against multiple data sources, and a peer-debriefer examined the data and reviewed the analysis. Negative case analyses (Carspecken, 1996) lent further support to the validity of the researcher's interpretation of the data. Connections were made between the themes developed in the first round of formal analysis of data and the latter analysis of VNOS-C data to explain changes in teachers' views of NOS.

Findings and Discussion

Prior to the summer institute, administration of VNOS-C questionnaires and interviews revealed teachers lacked a consistent, overarching framework for their views of the nature of science, and held a number of misconceptions (e.g., theories become laws), similar to findings in earlier studies (e.g., Schwartz & Lederman, 2002). Less than 15% of the teachers exhibited internalization of individual NOS aspects across their responses to different items. Many participants failed to exhibit internal consistency, often contradicting themselves in their responses to the VNOS-C. For example, 80% of teachers acknowledged the role of scientists' subjectivity and the influence of societal norms and values on science; however, 35% of those same teachers felt data collection was "objective." Table 1 below provides examples of views held by teachers that were consistent or inconsistent with reform characterizations of NOS. The percentages in each case are not additive, given participants were found to express *both* views in some cases.

Table 1: Participants' Views of NOS (Pre-term)

Views consistent with reforms	Views inconsistent with reforms
Empirical NOS	
Science relies on both observation and inference (64%)	Science relies on direct observations (12%)
Methods of Science	
Scientists utilize multiple methods including modeling, observation, and experiments (41%)	Experiments are required to advance scientific knowledge (59%) Scientists utilize the "scientific method" (16%)
Tentativeness	
(All) scientific knowledge is subject to change (68%)	Laws are proven or absolute and immutable (32%)
Subjective NOS	
Science is a human endeavor, influenced by subjectivity (80%)	Science is objective (16%)
Socio-cultural embeddedness	
Science reflects socio-cultural norms and values (80%)	Science is universal (20%) Science (objective) is separate from humans (subjective) who engage in it (12%)
Creative NOS	
Science, by its nature, involves the use of creativity and imagination (65%)	Data collection is objective, therefore not creative (35%)
Function and Relation of Theory and Law	
Theories and laws are fundamentally different forms of knowledge (4%)	Theories become laws (32%) Theories are less certain than laws (40%)

Analysis of VNOS-C post data indicated the majority of teachers' views of NOS were not changed as a result of their participation in the summer institute. Few changes (eight) in teachers' views of the nature of science were evident, and in only seven teachers' (28%) responses to the VNOS-C. Only half of these changes represented shifts toward views of NOS consistent with those outlined in the reforms, while the remaining four represented a change from a view that had been aligned with the reforms to one that was now inconsistent with them. Table 2 provides a summary of the eight shifts in participants' views of NOS identified in the analysis.

Table 2: Eight changes evident in participants' views of NOS

Pre-administration view	**Post-administration view**
Empirical NOS	
Science is based on what can be directly observed and measured	Science is based on what you can observe/measure or infer through reasoning
Methods of Science	
Observations are a valid form of scientific investigation (n=3)	Experiments are required in order for science to advance (n=3)*
Tentativeness	
Species characterizations *should* be agreed upon/ definitive	Species characterizations are dynamic, rather than absolute in nature
Socio-cultural embeddedness	
Science is influenced by society and culture	Science is universal*
Creative NOS	
Testing and data collection are not creative	Data collection involves creativity in devising how to collect data
Creativity is involved in all stages of scientific investigation	Data collection is objective*

*Denotes a shift toward a view inconsistent with the reforms

Several factors contribute to the limited impact the program had on teachers' views of NOS in terms of helping them develop views consistent with reforms. These include differences between NOS as described in the reforms and defined by the program developers; the status of NOS as an instructional objective of the course; the approach to teaching NOS utilized by facilitators; and the classroom norms followed by teacher participants and facilitators alike.

The phrase 'NOS' held a slightly different meaning when used by Physics faculty who developed the course than the way in which it is articulated in the reforms. McDermott and DeWater refer to the nature of science as understanding "not only what we know, but on what evidence and through what lines of reasoning we have come to that knowledge (2000, p.245). Not all aspects of NOS emphasized in the reforms are encompassed in this view. Table 3 indicates the aspects of NOS advanced in the reforms emphasized in the program's curriculum materials (laboratory manual).

Table 3: Curricular emphasis on aspects of NOS advanced by the reforms.

NOS Aspect:	**Curricular Emphasis:**
Empirical basis for scientific claims	Teachers are asked to provide evidence to support their ideas and to identify/evaluate claims that go beyond the evidence.
Tentativeness of scientific knowledge	Teachers are instructed that they may change their ideas in light of new evidence. Teachers are asked to consider what can/ cannot be concluded from available evidence.
Role of creativity and imagination in science	Not emphasized
Subjective and theory-laden aspect of science	Not emphasized
Socio-cultural embeddedness of science	Not emphasized
Distinction between observation and inference	Teachers are specifically asked to make observations and inferences.
Lack of universal, recipe-like "scientific method"	Teachers engage in construction of models, experiments, and simple observations.
Function and relation of theory and law	Not emphasized

That individual teachers' views of NOS aspects *not* emphasized within the program remained unchanged is not surprising. However, findings indicate teachers' views of several aspects of NOS that *were* addressed within the formal curriculum remained unchanged as well. In some cases these were the same aspects about which many of the teachers already held views consistent with the reforms prior to their participation in the course (e.g. reliance on empirical evidence). However, the 32% of teachers who embraced a view of scientific laws as being supported by absolute proof in both pre- and post- administrations of the VNOS-C provide evidence that their experience in the program was insufficient to promote conceptual change in regard to their understanding of the tentative NOS.

A contributing factor is the status of NOS in regard to the goals of the program, and the facilitators' awareness of NOS as an instructional goal. Though NOS had been identified as an 'intellectual objective' of the course by course developers, not all instructional staff members articulated NOS as an intended learning outcome of the curriculum. While all nine facilitators emphasized science content and processes as primary objectives of the course, only three described an additional goal for teachers to understand "what science is and how it is developed," "scientific thought," or science as a "field of inquiry." This limited the degree to which NOS received emphasis by facilitators, in comparison to the focus on science content and processes. Only rarely did facilitators deviate from the NOS emphasis within the published curriculum materials, extending the discourse on NOS during formative "check-out" sessions with teacher participants. However, on several such occasions, facilitator's own views of the function and relation of theory and law served only to reinforce the misconceptions held by teacher participants that theories become laws.

The findings of this study highlight a mismatch between the instructional approach to teaching NOS and the context of the course itself. Within the course, discourse on NOS was limited to the context of the classroom investigations teachers conducted, rather than extending to the broader context of science, as practiced by professionals. Data indicate, however, that the teacher participants did not view their learning activities as 'real science' and thus did not associate the nature of these activities (school science) with the nature of science (real science).

Indeed, when asked in interviews how what they did in the program was similar to what scientists do, several teachers indicated that they "had no idea" what scientists actually did. In one participant's words, they were simply learning the "grammar of science." As such, it is not surprising their experiences in the course had little impact on their views of the nature of science.

Furthermore, the norms and values of the classroom (school science) were often at odds with the norms and values of science, serving as a barrier to enhancing teachers' views of NOS. For example, knowledge building practices of teachers differed from knowledge building practices of science in several critical ways. Despite facilitators' attempts to promote norms and values of science (e.g. respect for evidence) teachers relied instead on norms and values of the classroom (e.g. desire for correct answers). For example, when teachers encountered pairs of magnets that did not repel each other, rather than giving priority to that evidence, they simply sought out magnets that "worked." In some cases, facilitators encouraged them to do this as well. Thus, facilitators' instructional strategies often had unintended consequences of reinforcing such classroom norms, rather than helping teachers adopt scientific practices.

Sociocultural theory, then, provides a useful framework to explain the relative lack of change in teachers' views. The norms and values teachers held as members of "school" culture were antithetical to the norms and values of "scientific" culture being promoted by the facilitators. Both scientists and learners (who in this study are teachers) function as socioculturally defined groups who have ways of thinking that are shaped by the norms and traditions of their community of practice (Wenger, 1998). As Hogan and Maglienti (2001) emphasized, reasoning practices originate within the cultural practice of various groups. Such "cultural activity occurring on the social plane becomes internalized as tools for cognition on the personal plane" (Vygotsky, 1978, cited in Hogan & Maglienti, 2001, p.665).

Emphasis on the nature of teachers' own investigations did not successfully improve their understandings of the nature of science. That is, their understandings about their own work did not transfer to their understandings of the nature of science. Hogan (2000) draws attention to a distinction between such "distal" and "proximal" understandings of NOS:

> Distal knowledge of the nature of science refers to students' knowledge about the protocols, practices, and products of the professional scientific community. Proximal knowledge of the nature of science refers to students' understanding of and perspectives on the nature of their own science knowledge-building practices and the scientific knowledge they form and encounter. Proximal knowledge of the nature of science is tied to students' school contexts of knowledge production. (2000, p. 52)

Such forms of knowledge are related to the norms and standards of communities of practice. While learners engage in scientific investigations in classrooms, the school community itself is the predominant community of practice in which students participate (Lave & Wenger, 1991, cited in Hogan & Corey, 2002). Thus, when the norms and standards of classroom practice are inconsistent with those of science, learners' proximal knowledge of the nature of science may be inconsistent with learning objectives relating to distal knowledge of the nature of science.

Implications

These findings call into question the assumption that reflection on *classroom-based science investigations* alone is an effective means for promoting understandings of the nature of science. That is, when classroom-based investigations do not accurately reflect the ways in which scientists go about their work, reflecting on these "school science" experiences does not allow one to develop an understanding of what scientists do. One implication is that reflection not be limited to the context of the science activities learners conduct within the classroom, but also extend to link learner's classroom activities to the activities of professional scientists. This supports the view that science instruction acts as a process of enculturation (Driver, Asoko, Leach, Mortimer, & Scott, 1994) that takes learners "beyond the boundaries of their own experiences to become familiar with new explanatory systems, ways of using language, and styles of developing knowledge" (Hogan & Corey, 1991, p.215).

The implication of this perspective for research is that the NOS understandings be investigated not only in terms of the curriculum or instruction, that is, the nature of the *teaching* and *tasks* in which learners are engaged and how those differ from the tasks in which scientists engage, but also the norms and values that learners share as a community of practice and how these compare to the norms and values held by scientists as a community of practice.

This study draws attention to the need for improved communication between science educators and scientists regarding teacher education, specifically relating to the nature of science as an instructional objective. Both education and science content courses play important roles in the preparation of teachers. When conflicting messages about the nature of science are presented within these two contexts, it is likely teachers will fail to internalize views of NOS that align with contemporary reforms. Different interpretations of the phrase "nature of science," and disagreement as to what the nature of science *is* pose a barrier to effective collaborative efforts. While reforms have promoted generalized and non-controversial aspects of NOS in order to avoid "paralysis of practical action" (Rudolph, 2000), it is evident in this particular context that there is not alignment between the reform characterizations of NOS and that of science faculty.

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