

ELEMENTARY TEACHERS' PEDAGOGICAL CONTENT KNOWLEDGE FOR TEACHING THE NATURE OF SCIENCE: AN EXAMINATION OF TEACHERS WHO ARE EFFECTIVE IN IMPROVING THEIR STUDENTS' VIEWS

This study explored components of pedagogical content knowledge (PCK) of three teachers who were found successful at improving elementary students' views of NOS. Assuming PCK for NOS to be similar to PCK for other science topics, we drew from the model of PCK developed by Magnusson, Krajcik, and Borko (1999). Our efforts reflect a critical re-examination of data from a previous study, or what Heaton (1998) refers to as secondary analysis, and relied on the following data sources (1) field notes and transcripts from professional development sessions, (2) videos, lesson plans, and field notes from observations of teachers' classroom teaching of NOS (3) video stimulated-recall interviews conducted with teachers following classroom observations (4) videos and transcripts from teachers' presentations of their teaching experiences and professional conferences, (5) teachers' written contributions to professional publications, and (6) a focus-group session held with teachers at the conclusion of the project. We found teachers held strong intentions to teach NOS, used strategies modeled for them in workshops with their students, adapted their curricula to emphasize NOS, supported student discourse about NOS using "kid-friendly" language, and used a variety of instructional strategies. Though the teachers informally assessed NOS views, they were less effective in formally assessing students' understandings. Recommendations include the design of educative curriculum materials and assessment tools to support the development of teachers' PCK for NOS and their ability to use assessment data to guide their NOS instruction.

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Introduction

U.S. science education reforms (e.g., AAAS, 1990, 1993; NRC, 1996) recommend K-12 students develop an understanding of nature of science (NOS); yet, a challenge in reaching this goal is that many teachers do not have adequate understandings of NOS themselves (Abd-El-Khalick & Lederman, 2000). Teachers' lack of experiences with science can limit their ability to plan and implement lessons that will help students develop an image of science that goes beyond the familiar 'body of knowledge' (Gallagher, 1991). Furthermore, even when teachers understand NOS, a number of factors have been shown to mediate and constrain the translation of their understandings about NOS into their practice. These include pressure to cover content, classroom management or organizational issues, concerns for students' abilities and/or motivation, institutional constraints, teaching experience, and lack of resources and experiences for assessing NOS understandings (Abd-El-Khalick & Lederman, 2000; Akerson & Abd-El-Khalick, 2003).

Much research to date regarding elementary teachers' views of NOS has been carried out with preservice teachers who, Lunn argues, "have had no opportunity to accommodate science into their professional practice and a reflective understanding of their own practice" (2002, p.650). Additionally, while there has been a great deal of focus on improving the views of NOS of teachers in teacher education, according to Bartholomew, Osborne and Ratcliffe, "teaching the nature of science in schools has been much discussed and debated but underexplored where it matters--in the classroom (2004, p. 656). Given teaching experience is one of several variables shown to mediate and constrain the translation of teachers' views into their teaching practice, it is problematic that much of the research that investigates teachers' abilities to teach NOS has been focused on relatively inexperienced teachers. Indeed, the proposed models of pedagogical content knowledge (PCK) for NOS are derived from work with novice teachers (Schwartz & Lederman, 2002), who arguably would not have well-developed PCK for NOS, given "PCK usually develops as a result of extensive and extended experiences teaching a certain topic" (Abd-El-Khalick & Lederman, 2000, p. 693).

Within research related to the teaching and learning of NOS, there is a need to focus on experienced classroom teachers who have demonstrated effectiveness in teaching NOS. Such "expert" perspectives might better inform our understanding of how to support novice teachers in learning to teach NOS, as well as provide insight into the nature, source, and development of teachers' PCK for NOS. Currently, there are few examples in the literature of "effective" NOS instruction by classroom teachers, and fewer still that utilize student outcomes as criteria to determine effectiveness of teachers' NOS instruction. For example, judgments made by Bartholomew et al. (2004) about the 'effectiveness' of teachers' instruction were not based on the impact of that instruction on students' views of NOS. As the authors explain:

...whereas we had initially sought to examine the success of these approaches at developing an understanding of the themes in the students, such an aim was impractical because of the enormous variation between teachers in their ability to introduce and explore 'ideas-about-science' with their students (p. 662).

Though study participants were relatively experienced classroom teachers, they were nonetheless inexperienced in teaching NOS, having participated in four workshops over a three-month period.

Our own work with elementary teachers led to substantial improvements in teachers' understanding of NOS and their ability to teach NOS, but only after three years of participating in a professional development program targeting NOS and inquiry (Akerson & Hanuscin, 2007). While our initial research focused specifically on the design and impact of the professional development on teachers' views of NOS and ability to teach NOS, we posit that there is more that can be learned by examining the practices of these teachers. Understanding the way in which experienced teachers, specifically those who effectively teach NOS to their students, transform their understanding of NOS into forms accessible to K-6 learners can inform future efforts in this area. The purpose of this paper is to examine the pedagogical content knowledge (PCK) for teaching NOS of elementary teachers who have successfully improved the NOS views of their students. Specifically, we ask:

1. How do teachers transform their understandings of NOS into representations that are accessible to K-6 learners?

2. How do teachers assess the effectiveness of their teaching of NOS and its impact on students' ideas about NOS?

Literature Review

The Nature of Science

The 'nature of science' (NOS) refers to understanding science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). As Driver, Leach, Millar, and Scott emphasize "understanding of the nature of science is necessary if people are to make sense of the science and manage the technological objects and processes they encounter in everyday life... [and] make sense of socio-scientific issues and participate in the decision-making process" (1996, p. 16). NOS has been underscored as a critical component of scientific literacy in science education reforms (AAAS, 1990, 1993; NRC, 1996) as well as in a position statement of the National Science Teachers Association (NSTA) (2000). Seven aspects of the nature of science common to these reforms include: (a) scientific knowledge is both reliable (one can have confidence in scientific knowledge) and tentative (subject to change in light of new evidence or reconceptualization of prior evidence); (b) no single scientific method exists, but there are shared characteristics of scientific approaches to science, such as scientific explanations being supported by empirical evidence, and testable against the natural world; (c) creativity plays a role in the development of scientific knowledge; (d) there is a relationship between theories and laws; (e) there is a relationship between observations and inferences; (f) though science strives for objectivity, there is always an element of subjectivity in the development of scientific knowledge; and (g) social and cultural context also play a role in the development of scientific knowledge. It should be noted that these characterizations of NOS are a simplified and noncontroversial account of what remains an area of much disagreement and debate among historians, philosophers, and sociologists of science (Duschl, 1994), though there is some degree of consensus regarding the importance of these ideas about science for science education (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). Because K-12 teachers are expected to help students develop understandings of NOS in line with those described in reforms, these provide a useful framework for teacher education and research in considering elementary teachers' preparedness to teach NOS.

Elementary Teachers' View of NOS

Science reform documents recommend that scientifically literate adults should understand how science distinguishes itself from other ways of knowing (AAAS, 1990, 1993; NRC, 1996). In order to help their own students develop scientific literacy, teachers should be scientifically literate themselves. Yet, research conducted since the publication of these reforms indicates that elementary teachers often have naïve views of the nature of science. Abell and Smith (1994) reported teachers "fail to see science as a unique discipline involving a specific kind of knowledge about the world...the discipline takes on an almost heroic stature" (p. 481). Abd-El-Khalick (2001) found many preservice elementary teachers believe that science "relies solely on observations of the natural world (or "facts") to the exclusion of other more subjective human elements, such as beliefs and opinions, which are characteristic of other modes of inquiry" (pp. 221-222). In a study conducted by Murcia and Schibeci (1999), primary student teachers appeared to hold the belief that knowledge claims with sufficient experimental evidence can be accepted as truth. Only a minority apparently had a limited appreciation of the tentative nature as they mentioned the need for continuing research to attain further evidence. On the other hand,

a majority was reported to “view science as a relatively static accumulation of information, rather than as a dynamic discipline” (Murcia & Schibeci, 1999, p. 1137). Furthermore, Mellado (1997) conducted case studies of preservice elementary teachers and found they “all had a deeply ingrained set of clichéd ideas on the empiricist scientific method” (p. 340).

Efforts to Improve Elementary Teachers' Views of NOS

Because understanding NOS is prerequisite to teaching NOS, science teacher educators have undertaken attempts to improve elementary teachers' views of NOS within teacher education programs and professional development. For example, Barufaldi, Bethel, and Lamb (1977) found that preservice teachers in the treatment group classes who experienced inquiry activities held better understandings of the tentative NOS than those in the control groups. Meichtry (1995) found that preservice teachers held largely incomplete understandings of NOS initially, and developed better understandings by participating in her course that emphasized the learning cycle and reflection on scientists' work. Bianchini and Colburn (2000) found that the course instructor (Colburn) played a pivotal role in focusing the students on NOS ideas, and recommend that educators continue to guide and support teachers as they use inquiry to help students understand NOS.

Akerson, Abd-El-Khalick, and Lederman (2000) found that an explicit, reflective approach to nature of science instruction enhanced preservice elementary teachers' views of NOS. This approach provides structured and guided opportunities for learners to examine and discern discrepancies between their NOS conceptions and those presented to them, clarify the presented NOS ideas and framework for themselves, and reflect on how specific aspects of NOS are illustrated by the curricular activities in which they participate through discussion and/or reflective journaling (see, for example, Abd-El-Khalick, 2001). A multitude of studies have provided additional evidence of the effectiveness of this approach in improving both preservice and practicing teachers' views of NOS (e.g. Akerson, et al., 2000; Akerson, Morrison, & Roth-McDuffie, 2007; Lederman, 1992, 1999). Moreover, recent work with in-service elementary teachers indicates that an explicit-and-reflective instructional approach, combined with classroom support for emphasizing aspects of NOS enables teachers to develop an understanding of NOS as well as abilities to teach NOS to their students (Akerson & Abd-El-Khalick, 2003; Akerson & Hanuscin, 2007).

Elementary Teachers' Ability to Teach NOS

As Lederman emphasizes, “it is one thing to teach teachers about NOS; it is a totally different endeavor to teach them how to teach NOS to their students” (Lederman, 2007, p. 870). Researchers over the past several decades have recognized a need for investigation of elementary teachers' views of NOS and classroom practices (e.g., Fleury & Bentley, 1991). Despite this, few studies have examined elementary teachers' abilities to teach NOS, particularly in terms of the impact of their instruction on students' understanding. Indeed, teachers' effectiveness in teaching NOS has often been determined by considering the degree to which they provide students with opportunities to learn NOS through activities and classroom discourse, rather than the degree to which such opportunities are realized by students, resulting in improved views of NOS. For example, Bartholomew, Osborne, and Ratcliffe characterized effectiveness of teachers' NOS instruction based on the degree to which lessons provided “(a) an opportunity for explicit student consideration of elements of one theme or more; (b) active student engagement with the topic at

hand in one form or another; and (c) the opportunity to engage in epistemic dialogue that provided an opportunity for the construction and evaluation of reasoned arguments which related ideas to their supporting evidence” (2004, p. 663).

Several investigations which *have* examined student outcomes, however, provide evidence that with K-6 students, just as with teachers, NOS instruction must be explicit, rather than implicit. For example, Khisfe and Abd-El-Khalick (2002) found that 6th grade students who engaged in inquiry-based learning *and* had explicit instruction about NOS improved their views of NOS, while those who engaged in inquiry-based learning where NOS was an implicit component of instruction did not. Similarly, Akerson and Abd-El-Khalick (2003, 2005) found that despite immersion in inquiry-based instruction, 4th grade students’ views were not impacted when the teacher neglected to provide explicit instruction about NOS. Intentionally explicit instruction has also been found to impact understandings of beginning elementary students. A recent study by Akerson and Volrich (2006) found that a student teacher (Volrich) who had sufficient understanding of NOS, as well as intentions and motivation to teach NOS, could effectively implement strategies for explicitly emphasizing NOS within her instruction. This resulted in improved first graders’ views of the tentative, inferential, and creative NOS. The authors assert that Volrich’s prior experiences as a peer instructor in a physics course that emphasized NOS explicitly as part of the curriculum (see Hanuscin, Akerson, & Phillipson-Mower, 2006) helped her develop pedagogical content knowledge (PCK) for teaching NOS.

Pedagogical Content Knowledge (PCK) for NOS

Shulman (1987) first introduced the notion of pedagogical content knowledge (PCK) as a fundamental component of the knowledge base for teaching. PCK, according to Shulman, is what makes possible the transformation of disciplinary content into forms that are accessible and attainable by students. This includes knowledge of how particular subject matter topics, problems, and issues can be organized, represented, and adapted to the diverse interests and abilities of learners and presented for instruction (Magnusson, Krajcik, & Borko, 1999). Magnusson et al.’s model of PCK includes five components: (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum (goals & objectives/ curriculum and materials), (c) knowledge and beliefs about students’ understanding of specific science topics (prerequisite knowledge and student misconceptions), (d) knowledge and beliefs about assessment in science (dimensions of science learning to assess and knowledge of methods of assessment), (e) knowledge and beliefs about instructional strategies for teaching science (topic-specific activities, e.g., NOS; as well as subject-specific strategies, e.g., inquiry).

Consistent with this framework, Abd-El-Khalick and Lederman (2000) propose that in addition to adequate understanding of NOS, teachers’ PCK for NOS would include:

...knowledge of a wide range of related examples, activities, illustrations, demonstrations, and historical episodes. These components would enable the teacher to organize, represent, and present the topic for instruction in a manner that makes the target aspects of NOS accessible to pre-college students. Moreover, knowledge of alternative ways of representing aspects of NOS would enable the teacher to adapt those aspects to the diverse interests and abilities of learners.... [T]eachers should be able to comfortably discourse about NOS, design science-based activities that would help students comprehend those aspects, and

contextualize their teaching about NOS with some examples or 'stories' from history of science. (pp. 692-3)

In later work, Schwartz and Lederman (2002) proposed an emerging model of critical elements for the development of PCK for NOS and application of that knowledge in the classroom. According to these researchers, knowledge of NOS, knowledge of science subject matter, and knowledge of pedagogy are just three of the elements that blend to form PCK for NOS. They argue that to be able to teach NOS, teachers must intend and believe they can teach NOS, must believe that their students can learn NOS, and must have the knowledge base for teaching NOS (Schwartz & Lederman, 2002).

Despite the numerous investigations into the development of PCK throughout all disciplinary areas and science in particular (e.g., Gess-Newsome & Lederman, 1999), “the nature and development of teachers’ PCK for NOS is an area of research that has yet to be investigated” (Lederman et al., 2001). Several studies have alluded to the impact of interventions on teachers’ PCK for NOS (Akerson & Abd-El-Khalick, 2003; Akerson & Volrich, 2006), but have not investigated the sources, nature, and development of PCK for NOS in any systematic way. “Virtually no research has used the PCK perspective, which was so heavily researched during the 1990s, as a lens for research on the teaching of NOS” (Lederman, 2007, p. 870). While studies have often focused on individual components of PCK such as knowledge and beliefs about teaching NOS, there is a striking paucity of studies that have explored other components of PCK for NOS such as knowledge and beliefs about assessment of NOS.

Teachers’ Assessment of Students’ Understanding of NOS

While there has been much debate among science education researchers as to the best way to assess understanding of NOS for research purposes (Chen, 2006; Elby & Hammer, 2001; Lederman et al., 2002) teachers’ classroom-based strategies for assessing their students’ understanding of NOS has received little, if any, attention within the literature regarding teachers’ NOS practices (e.g., Bartholomew, Osborne, & Ratcliffe, 2004; Brickhouse, 1990; Schwartz & Lederman, 2002). Indeed, knowledge of strategies for assessing NOS has not been an explicit component of proposed models of PCK for NOS (e.g., Abd-El-Khalick & Lederman, 2000; Schwartz & Lederman, 2002). This omission is striking, given the current emphasis on “explicit” approaches to teaching NOS. For example, as Lederman et al. (2001) explain:

The term ‘explicit’ is used... to emphasize that teaching about NOS should be similar to teaching about any other cognitive learning outcome: NOS understandings should be intentionally planned for, taught, and *assessed* [emphasis added] rather than expected to come about as a by-product of teaching science content or process skills or of engaging students in science activities (p.137).

In other words, while science educators have advocated for approaches that specifically include assessment of learners’ NOS views, research has rarely taken into account teachers’ abilities to assess their students’ views of NOS in any in-depth manner.

Abd-El-Khalick & Lederman (1998) examined classroom assessment as component of preservice secondary teachers’ NOS practices, but reported that teachers did not formally assess NOS. Participants’ failure to assess their students’ ideas about NOS was considered a

“discrepancy between [their practices and] stated belief in the importance of teaching NOS” (Abd-El-Khalick, Bell, & Lederman, 1998, p.427). It is unclear, however, whether these prospective teachers simply neglected to implement strategies for assessing NOS or did not possess the necessary knowledge and skills to do so. The authors do not indicate whether or how these prospective teachers were prepared to assess NOS outcomes as part of their coursework.

In another study, Lederman, Abd-El-Khalick, Bell, and Schwartz (2001) set out to characterize participant’s attempts at NOS instruction, including the NOS aspects addressed, the planning of instructional objectives related to these aspects, the approaches used to teach these aspects, and the types and relative numbers of assessments administered relative to the NOS aspects taught. Only one mention of assessment practices was made, however, of a single participant who wrote “two exam questions aligned with his two objectives on scientific models (inference) and tentativeness” (p.152). The nature of this assessment and the way in which the teacher used the results of this assessment to inform his teaching are not specified, though the researchers claimed “preservice teachers in this investigation increased their explicit attention to NOS with respect to planning, classroom practice, and *instructional assessment* [emphasis added]” (p.156).

Schwartz and Lederman (2002) studied the abilities of two novice teachers to teach NOS. No attempts were made by the researchers to assess the impact of instruction on students’ views of NOS, and it appears that no formalized efforts were made by the teachers to do so, either:

As for student achievement of NOS understanding, Rich was confident his students had gained a basic understanding [of NOS] by the end of the three weeks of activities. His assessment was formed through questioning during class (p. 224)

The researchers considered both teachers successful, nonetheless, because they planned for and emphasized NOS explicitly in their teaching.

More recently, Bartholomew et al., aimed “to develop teachers’ confidence and expertise both to use appropriate teaching strategies and *appraise learner outcomes* [emphasis added]” (2004, p. 662). The authors held a series of four workshops held over a three-month period, the purpose of which was to provide teachers an “opportunity to explore, plan, and develop materials for the explicit teaching of [the nature of science]; to explore the pedagogical implications; to examine teachers’ own understanding of the nature of science; and to *consider methods of evaluating the learning outcomes for pupils* [emphasis added]” (2004, p. 661). In their manuscript, the authors provide several examples and sources of lessons they used to model teaching of NOS; however, they provide no specific information about the methods of evaluating NOS learning outcomes explored by the teachers. In their descriptions of teachers’ implementation of lessons, several speculations are offered by teachers about how they *might* evaluate students’ understanding, but it is not clear whether and how teachers formally assessed students’ learning outcomes. For example, the researchers report:

After the lesson Mike spoke briefly about his perceptions of the lesson, and said that in order to evaluate his students’ learning he would test their understanding of the words “observation” and “inference.” He also commented that “on the whole he felt the lesson was successful, and a “safe bet” since it had worked well with a number of other groups too.” On Mike’s terms, then, it would appear that this lesson achieved its intended outcomes... (2004, p. 672).

Thus, we can infer teachers' perceptions of the effectiveness of the lessons (whether they "worked") were based more on informal discussions rather than on deliberate efforts to determine how students' ideas about NOS had been impacted.

In the present study, we hope to address these gaps in the literature by specifically focusing on the ways in which teachers transform NOS into forms accessible to students as well as the way in which they assess the impact of their instruction. By examining the instructional and assessment practices of teachers who are effective in improving their students' views of NOS, we hope to further illuminate the nature, sources, and development of PCK for NOS.

Methods

Research Design

Our efforts reflect a critical re-examination of data from a previous study (Akerson & Hanuscin, 2007), or what Heaton (1998) refers to as secondary analysis. While already a common and generally accepted mode of inquiry in quantitative research, secondary analysis is increasingly being utilized in different forms for qualitative inquiry (Heaton, 2004). Within this framework, researchers utilize "retrospective analysis of the whole or part of a data set from a different perspective, to examine concepts which were not central to the original research" (Heaton, 1998).

Our initial study was concerned with assessing the impact of a three-year professional development program on teachers' views of NOS and instructional practices, as well as the impact of teachers' instructional practices on students' understandings of NOS. A primary interest was identifying features of professional development that effectively support teachers in developing their abilities to teach NOS. In this study, we focus on the broader question, *what can we learn from examining the PCK of elementary teachers who are "effective" in teaching their students about NOS?* Specifically, we examine (1) the ways in which teachers transformed their understandings of NOS into representations that are accessible to K-6 learners, and (2) how they made judgments about their own effectiveness in teaching NOS. In this way, our work transcends our original study by examining teachers' practices through a PCK lens. This is a significant departure from prior research in this field, in which 'effectiveness' has been determined from the perspective of researchers (e.g., Bartholomew, Osborne, & Ratcliffe, 2004). In this study, we seek to understand teachers' own perceptions of their practice and its impact on their students.

As Thorne (1994) emphasizes, in presenting a secondary analysis, researchers should include an outline of the original study and data collection procedures, together with a description of the processes involved in categorizing and summarizing the data for the secondary analysis, as well as an account of how methodological and ethical considerations were addressed. Appropriately, we provide this account in the sections that follow.

Context

Learning Science by Inquiry was a single-school professional development program that focused on developing teachers' understanding of the nature of science (NOS) and scientific inquiry and empowering them to teach in ways that foster students' understandings of these as well. Six of

the fourteen classroom teachers at Parker¹ Primary School participated in the program through a series of monthly half and full-day workshops (n=19) over three years.

During initial workshops, teachers were introduced to aspects of the NOS advanced by the reforms (AAAS, 1990, 1993; NRC, 1996) and participated in inquiry-based experiences designed to illustrate the nature of science. Additionally, teachers examined their curriculum to identify whether and how NOS and inquiry were emphasized. As Lederman, Schwartz, Abd-El-Khalick, & Bell (2001) stress, simply providing teachers with pre-packaged activities is not effective in improving their abilities to teach NOS; rather, meaningful professional development equips teachers with strategies for revising and adapting their existing curricular materials to more accurately reflect the nature of science and scientific inquiry. Consistent with this recommendation, workshop sessions focused on strategies for teaching NOS and inquiry in the elementary classroom and included collaborative planning sessions for adapting curriculum.

Throughout the three years of the program, project staff (first and third authors) provided support to teachers by teaching model lessons, co-teaching collaboratively planned lessons, observing and providing feedback to teachers about their instruction, and assisting in preparing presentations and publications of teachers' work through professional organizations (conferences, monographs, etc.). Through our research, we examined the impact of the professional development on teachers' understanding of NOS and instructional practices, as well as the impact of teachers' instruction on students' understandings of NOS (see Akerson & Hanuscin, 2007). We found that though the teachers held misconceptions about NOS at the outset of the program, their views improved substantially over the course of their participation. In addition, they began to emphasize NOS in their instruction through the support of the professional development facilitators. We found that the monthly workshops, coupled with individualized classroom support, successfully improved teachers' NOS views and teaching practice. The elementary students in these teachers' classes generally held naïve views of most of the NOS elements at the beginning of the school year, but held improved views of most aspects at the conclusion of the school year. This assertion relied on evidence gathered for research purposes, namely student interviews conducted using the VNOS-D (Lederman & Khishfe, 2002). We consider these teachers 'effective' because we determined, through research, that their instruction impacted students' views; however, in re-examining our data we were interested in knowing how teachers perceived their own effectiveness, particularly in how their assessment practices inform their teaching of NOS.

Data Sources

The nature, richness, and diversity of available data from the first study meet Heaton's criteria of compatibility with the secondary analysis. Furthermore, the first and third authors' roles as primary analysts in the first study position us to have access to the original data in line with the original informed consent of participants. We selected the following data sources from our first study for use in our secondary analysis: (1) field notes and transcripts from PD sessions, (2) videos, lesson plans, and field notes from observations of teachers' classroom teaching of NOS (3) video stimulated-recall interviews conducted with teachers following classroom observations (4) videos and transcripts from teachers' presentations of their teaching experiences and

¹ Pseudonyms are used for all participants

professional conferences, (5) teachers' written contributions to professional publications, and (6) a focus-group session held with teachers at the conclusion of the project.

Secondary Analysis

Our purpose was to verify theories and propositions based on qualitative data, rather than generate a (new) grounded theory. As such, we utilized modified analytic induction (Bogdan & Biklen, 1998; Taylor & Bogdan, 1984) with Magnusson et al.'s (1999) model for PCK serving as our coding paradigm. We began with a thorough review of all data sources, assigning codes and making analytic memos to denote instances relevant to teachers' PCK for teaching NOS. Matrices were used to track these instances across multiple data sources for individual teachers, allowing us to identify gaps, overlaps, patterns, and trends. As assertions were generated, we actively searched the data for negative cases, modifying our assertions to account for these as necessary. Independent examination of the data by each of the researchers further lent credibility to our findings.

Findings

In the sections that follow, we outline our findings according to the five components of PCK identified by Magnusson et al. (1999).

Orientations toward Science Teaching

Teachers' knowledge and beliefs about the purposes and goals for teaching science comprise their orientation toward science teaching, which plays a central role in "decision-making relative to planning, enacting, and reflection upon teaching" (Magnusson et al., 1999, p. 102). Though their orientations toward science teaching were initially activity-driven, at the conclusion of a three-year professional development program (Akerson & Hanuscin, 2005; Akerson & Hanuscin, 2007) each of the teachers had shifted toward an inquiry orientation. As Charlotte explained initially, she relied on science activities because "...mostly at this level I just want them to have an overall enthusiasm about [science] and to be curious and to explore." She and Carrie both agreed that at the primary level, learning science content was not as important as involving students in hands-on experiences. As she stated, "I know they're not gonna come away remembering a lot—but I feel like it's a start for them." Though similarly activity-driven in her orientation, Miranda, who taught at the intermediate level, put a greater emphasis on learning content.

As Borko and Putnam (1996) emphasize, teachers' beliefs influence their continued professional development. It should be noted that they each entered the professional development project with a strong motivation to improve what they each believed to be their weakest area instructionally. Thus, they were amenable to adopting new ways of thinking about teaching and learning science. Conversations among teachers during a final debriefing at the end of the project revealed teachers' developing rationales for teaching science as inquiry and emphasizing the nature of science.

Researcher: We've been talking about the nature of science—why do you feel it's important to teach that? What would you explain—what's motivating you?

Charlotte: For me, it's like giving the kids the empowerment that they can do this on their own—I think we all started in the place that science is this 'other' thing and that we were all kind of intimidated by it, and having the kids see themselves as scientists, and be

willing to try out an idea, knowing that it could work or not—but not having that fear—that’s where I come from. It’s more how people really *live*—and have science be exciting.

Miranda: I think for me, it was—I remember when I took my methods class for science, it was a lot different—and I was like *this is really neat, there are some really neat things*—I felt like I left with some good ideas about it, but then, when I actually got to the classroom and I did my first year of science I kind of felt *oooh...this is hard, I don’t like this book, I don’t like this*, and I felt kind of icky about it so I would just push it to the side, like, *well, it’s OK if we get to just a little bit of it*. And then from doing this, I feel it to be more of a priority for me, and I find that the kids enjoy it and like it—I think it made me realize more of the importance of [science]. It gave it a much more important place in my classroom than it was to me a few years ago. And I think this method is just—I don’t know.

Carrie: I initially did it because I never liked teaching science, and I feel like I’ve done a poor job of it in the past. And maybe because I’ve done, you know, some of those activities that are described in the one article—they’re hands-on, but they’re not really learning anything—I felt like this would be good for me, and I think it has, and I think what’s happened is, it’s evolved into me realizing, like Charlotte says, this is really how people learn, and so I’ve gotten really excited. I think there’s a lot of teachers who do not teach science at all—or their idea of teaching science is putting a video in and watching it, and I think part of it is denial—I think there’s been so much emphasis on math and reading, I think we’d be shocked if we knew how little [time] they are spending on science, and I think that it’s going to change—unfortunately because of the testing aspect... I know teachers who don’t teach science—maybe they’ll read a story or something and think that’s science.

[Transcript 5.13]

Each of these teachers had the clear intention to teach NOS, which Schwartz & Lederman (2002) emphasize as important. Teaching science-as-inquiry provided opportunities for teachers to convey the excitement of scientific inquiry to students as well as a venue for addressing the nature of science explicitly. However, teachers had to overcome the hurdle of a science curriculum and textbook that did not emphasize either of these in meaningful ways.

Knowledge and Beliefs about Science Curriculum

Teachers’ knowledge of both the mandated goals and objectives of science teaching (e.g., standards and guidelines) and the programs and curriculum materials relevant to teaching a particular domain of science comprise another component of PCK. While the three teachers we studied had developed a firm grasp of the goals and objectives for teaching both the nature of science and inquiry, as defined by national and state standards, they found their adopted textbook materials insufficient for providing opportunities for students to meet these standards. As a result, teachers continued to request additional lessons and activities to teach NOS to their students. Several such activities were modeled for teachers both within workshops and in their classrooms as part of the professional development, however a goal of this modeling was to demonstrate explicit and reflective strategies that could be used in all kinds of science lessons.

Overall, teachers readily implemented activities for teaching NOS that were modeled for them by workshop facilitators, though some novel examples of teaching NOS were evident in their

practice. To accomplish this, they spent a great deal of time adapting their curriculum to be more consistent with their inquiry-orientation toward teaching science, as well as the goals and objectives for science as inquiry (Akerson & Hanuscin, 2005; Akerson & Hanuscin, 2007). This work was largely influenced by teachers' beliefs about their students' science knowledge and abilities.

Knowledge and Beliefs about Students' Understanding of Specific Science Topics

A third component of PCK includes teachers' knowledge and beliefs regarding their students—including such things as the prerequisite knowledge needed for learning a new concept and areas of difficulty or student misconceptions related to that concept. Teaching science as inquiry definitely required more class time than implementing cookbook science activities—nonetheless, teachers viewed this time as essential to students' developing understandings. As Miranda explained,

Having more time to study things has made a bigger difference, too, because it's given them a chance to get interested, you know—like the simple machines unit, we spent SO long on that, and that was part of the reason why their understanding was so good, but also because it gave them more time to explore and investigate and put the puzzle together on their own. [Transcript 5.13]

Despite teachers' belief that students were capable of learning through inquiry, they nonetheless questioned the appropriateness of using the same language for NOS they used in the workshops with elementary students. In one of the first-year workshops during which teachers were introduced to the nature of science, they questioned whether the use of the phrase “nature of science” was necessary and/or appropriate for use with elementary students. The facilitator, an invited speaker and expert in the nature of science explained to them that it was not explicitly using the phrase “nature of science” but being explicit about the *ideas* about the nature of science that was critical:

I don't even call it “nature of science” with kids, but I use some of these words, or some form of these words. You want kids to know that what we believe in science can change, for creativity you can say that scientists are human beings trying to come up with an explanation of the world, and when you do that you are creating ideas. In terms of our backgrounds, things that make us ourselves fit into creativity. You come up with different ideas because of your own background. Observation and inference may be terms you can use with kids—kids can make an observation, and then infer the meaning. Science interacting with society—sociocultural. Empirical means that scientists collect data. Use whatever words work that help your students understand the underlying concepts. [Transcript 5.16]

Though they questioned the appropriateness of the vocabulary, they nonetheless believed their students were capable of learning the ideas. Following this episode, teachers initiated the creation of a series of posters for their classrooms that employed what they, in their professional experience, believed were age-appropriate terms for each of the aspects of the nature of science to which they had been introduced. For example, like the facilitator, they indicated that science was based on “data” and “evidence,” versus referencing the “empirical basis of science”. Table 1 provides examples of the wording teachers used to communicate to students the aspects of NOS they had learned through the professional development. In this manner, teachers' knowledge of their students and context helped them translate the subject matter (NOS) into a form more accessible to their students.

Table 1. Reform-Based Conceptions of the Nature of Science as Translated by Teachers

Aspect of NOS	Kid-Friendly Terms
Empirical	Scientists collect data and use evidence to explain their ideas
Tentative	Scientists can change their ideas
Subjective	Scientists use their personal perspectives when they think about their problems and data
Creative	Scientists create new ideas
Observation/Inference	Scientists interpret their observations and make inferences about them

Knowledge and Beliefs about Instructional Strategies for Teaching Science

A fourth component of PCK includes teachers’ knowledge and beliefs regarding instructional strategies. This includes subject-specific strategies, such as inquiry, as well as activities that can be used to help students understand a specific concept, such as the tentative NOS. As alluded to previously, inquiry was an important instructional strategy as it provided a venue for emphasizing various aspects of NOS explicitly. Teachers fostered discourse about NOS through debriefing sessions following student investigations, in which they asked students to reflect on their own inquiry and draw parallels between their work and the work of scientists. As the teachers described in their presentation at the annual meeting of the state science teachers’ association, they had focused the wording of the posters on “what scientists do”. Displayed throughout the year in teachers’ classrooms, the posters became a tool for making various aspects of the nature of science explicit and to help students operationally define NOS in the context of their inquiries. In other words, teachers used the posters to help students deepen understanding of their own knowledge construction in science class and link this to the broader scientific enterprise. For example, following a field trip to the NASA Challenger Center, Miranda’s students created Venn Diagrams that compared their actions in the simulation to the work of scientists. As Miranda explained, this consisted of “Talking about what scientists do, how different scientists use different things—things that kids can relate to. I also think it’s more—talking about science in different areas than *here’s what we’re doing, here’s the unit, here’s an activity*”. Carrie and Charlotte similarly held such debriefing sessions at the end of science lessons, focusing on the question “How is what you did [in this lesson] like what scientists do?”

Of course, it should be noted that teachers had spent a significant amount of time over the three years of the project adapting their curriculum materials and de-cookbooking science activities to make them more reflective of the nature of science and scientific inquiry. Had they not done this, it is likely that debriefing sessions following these lessons would not have provided opportunities for students to draw appropriate parallels between their own activities in the lessons and the activities of science. As Sandoval emphasizes, “school science [is often] so unlike professional science that we have no real hope to expect that students would develop robust epistemologies of science” (2005, p. 12). Thus, teachers’ knowledge of inquiry pedagogy and ability to create an inquiry-based classroom was essential to their teaching of NOS.

In addition to building connections between students' classroom inquiry and NOS, teachers used children's literature to address NOS explicitly. By calling attention to aspects such as subjectivity (or, as teachers put it, varying personal perspectives of scientists) in the context of familiar stories, teachers were able to assist students in recognizing these same qualities in scientific work. For example, Carrie utilized one of the books introduced in the workshop, *Seven Blind Mice* (Young, 1992) to help students understand the subjective NOS.

After reading the book, Carrie followed up by drawing students' attention to the subjective NOS. She began by talking about the background knowledge the white mouse had after he heard the other mice's observations and inferences about the "unknown thing." She asked, *How is this like what scientists do? Do scientists ever talk to other scientists? Do you think they share ideas and do you think by sharing their ideas with each other they are influencing each other's interpretations?* [Field notes 5.12]

The following fall, Carrie again used the book with her kindergarten students, to make this aspect of NOS explicit:

Carrie - You think they don't. They don't really think the same thing all the time? Do you think they always agree all the time?

Students - No.

Carrie - No. Because everybody is different and everybody think different. They are exploring looking for things. One scientist thinks different than the others. Just like how the mice did. Each mouse came back with different feeling. One of them said it was a fan and other said it was a rope. They all came back with different ideas. And do you think this happens to the scientist?

Students - Yes.

[Transcript 11.22]

Because the students could recognize subjectivity in this situation, the book facilitated considering how their own perspectives played a role in formulating ideas in science. Carrie would refer students back to this story as they debriefed subsequent science activities.

Charlotte also utilized the children's literature selections from the workshops to help her students understand the subjective NOS.

Actually, 'personal perspectives' I've emphasized a lot this year—and I think I mentioned, we started out using that *Professor Xargle* book—and I've used all those books. Just how something is described is it can depend on your experience with it... pointing out that names and titles and things are human-derived, and they're not just "there" [Transcript 5.13]

In subsequent lessons in her classroom, she compared *Professor Xargle's* (Willis, 1989) formation of inferences based on his observations to students' own activities, using observation and inference charts to make a distinction between the two.

Miranda, however, did not use children's literature to engage her students in discourse about NOS. When asked about the use of literature, Miranda indicated her difficulty in locating suitable and age-appropriate science-focused chapter books to use to introduce the nature of science to her students:

Miranda: If you're wanting to get students talking about NOS specifically, none of the science books I've looked at have talked about the nature of science. [Transcript 12.6]

Unlike Charlotte and Carrie, Miranda was teaching upper-elementary students, and relied more on chapter books in her teaching, versus the kind of picture books utilized in the workshops. The literature selections utilized in the professional development program arguably could have been used with upper-elementary students (indeed we used them to teach the *teachers* about NOS), and so this finding may perhaps reflect Miranda's inexperience using literature to teach science, more generally. For example, prior to the program both Carrie and Charlotte reported using children's literature often with their students during science lessons, while Miranda did not.

Knowledge and Beliefs about Assessment in Science

A fifth component of PCK includes teachers' knowledge and beliefs regarding the dimensions of science learning to assess as well as their knowledge of methods of assessment. As mentioned previously, we considered these teachers to be effective in teaching NOS because of the impact of their instruction on their students' understanding of NOS, as determined through pre-post assessments we conducted for research purposes (Akerson & Hanuscin, 2007). Arguably, teachers normally would not have researchers assessing learning outcomes of their students, and so we were interested in exploring teachers' own assessments of the impact of their instruction on students' understanding of NOS and the ways in which they gathered evidence of the effectiveness of their instruction.

Teachers' judgments about the effectiveness of their teaching were often based on self-perception of changes in their practice and the impact of their practice on students' learning—however, our secondary analyses reveals these perceptions were largely informed by informal assessment conducted by the teachers in the context of instruction. For example:

Carrie used formative assessment through the open-ended question to identify students' prior knowledge about force and motion and guide her instruction. For example, she began a subsequent lesson on "pushes and pulls" from her curriculum with a class discussion during which she raised the question, "How do we make things move?" She recorded the students' responses on chart paper so they could revisit their ideas after the investigation. She also concluded her lesson with an explicit debrief regarding the empirical NOS by asking students to think about what they had done in the context of scientists' work (Akerson & Hanuscin, 2007, p. 666).

A focus-group held at the conclusion of the program revealed that while teachers had enacted major changes in their instruction, they were struggling to enact parallel changes in their assessment. Indeed, Charlotte noted that she still found NOS outcomes difficult to assess:

Researcher: How much do you feel your students have understood about the NOS and how do you know?

Charlotte: It's hard to tell in some ways, because it's not something you can assess very easily... I mean, through discussion I hear them using the language more, I see them—I mean, the language is also up on the wall (referring to posters illustrating aspects of the nature of science that the teachers made)—and I see them kind of using that, or... whenever we do science, their attention—they look up there... in that sense, they have a better understanding.

Carrie: Well, and sometimes, even when we're doing something else they will bring it up or they will tie it in with something that they learned. I'm always really pleased, and maybe even a little surprised—

Miranda: --that they're making a connection.

Carrie: Yeah! And I feel like as they year has progressed, that's definitely happened for some of the kids. I still have children who go off on tangents or aren't quite grasping things, but there are a lot of kids I think are getting a grasp of what it's about—the things we've done this year. [Transcript 5.13]

What became evident in our re-examination of the data is that, while teachers had a growing sense that students were “making connections,” they ultimately relied on the results of our research assessments as evidence of the impact of their instruction on students' understanding of NOS. Teachers' use of discourse was identified by Bartholomew et al. (2004) as one of the five dimensions of effective practice for teaching students about NOS, and the type of reflective debriefing teachers conducted in the context of literature experiences and following classroom investigations arguably promoted students' understanding of NOS. However, teachers' use of these discussions as informal assessment strategies provided them with only a general sense of what their students understood about NOS. What is noticeably absent from teachers' practice is the use of formal and/or summative assessment strategies to determine NOS learning outcomes of individual students. Teachers *did*, however, use such assessments to determine learning outcomes related to students' understanding of other science content.

Discussion

Our first research question focused on ways that teachers transformed their understanding of NOS into forms accessible to their students. During the professional development, we modeled a variety of activities for teaching NOS using an explicit-and-reflective approach, and invited teachers to use these in their classrooms. Similarly, Schwartz and Lederman (2002) provided the beginning teachers in their study with an “activity pack” of NOS lessons that they had experienced, as learners, during their teacher education courses. They later observed that teachers relied on these alone in their instruction. In contrast, though the pedagogical repertoire of our three teachers was based on explicit-and-reflective activities modeled for them in their professional development program, they applied explicit-and-reflective strategies in novel ways in the context of inquiry-based lessons, literacy experiences, and field trips that they planned for their students. Despite this, however, teachers continued to request additional “NOS lessons” to implement in their classrooms. Appleton (2006) similarly described elementary teachers' desire for pre-packaged “activities that work” and suggests that, indeed, these may play an important role in the development of elementary teachers' PCK for teaching science. This perspective is inconsistent, however, with that of Schwartz and Lederman, who argued “...simply providing teachers with a packet of activities will not suffice to enhance their PCK for NOS. Meaningful professional development should empower teachers to develop and revise existing materials rather than simply to use the results of others' work” (2002, p. 231).

According to the *National Science Education Standards* (NRC, 1996), effective teachers must select science content and adapt their curricula to meet the interests, knowledge, understanding, abilities, and experiences of students. That is, teachers will rarely implement lessons “as is”. We find this to be especially true in terms of NOS. A review of elementary science curricula shows that such curricula do not suggest how to embed NOS within the content, therefore teachers require help in knowing how to adapt and embed NOS into their own science teaching (Akerson, Hanson, & Cullen, 2007). One curriculum we have found that does emphasize NOS is Full Options Science Systems (FOSS) Models and Designs Module. However, we have noted that teachers still must make adaptations to explicitly address the NOS aspects that are recommended

by the reforms (Akerson, Donnelly, & Riggs, in progress). This finding lends further credence to efforts to provide professional development for inservice teachers to enable them to build the knowledge and beliefs system component of PCK necessary to make the adaptations to embed NOS into any curriculum they may be required to use in their school systems. That is, teachers should be guided in realizing that NOS is not an “add on” but can be embedded in all science lessons.

Our findings highlight a need for “educative curriculum materials” for NOS, or K-12 curriculum materials that are intended to promote teacher learning in addition to student learning (Davis & Krajcik, 2005). Educative curriculum materials can help teachers add important ideas to their repertoires, including subject matter knowledge of NOS and students' likely ideas; however, such materials should remain flexible in promoting teachers' pedagogical design capacity, or their ability to use personal resources and supports embedded within curriculum materials to adapt curricula to meet the needs, interests, and abilities of their students. Educative curriculum materials, then, might help address the tension between teachers' desire for pre-packaged NOS “activities that work” and professional developers' desire to avoid providing a “bag of tricks”.

Furthermore, it should be noted that, given the design of the professional development program, teachers co-developed strategies for teaching NOS with inquiry—thus they were actively seeking epistemological consistency between “school science” and “authentic scientific inquiry.” As such, we emphasize teachers can't simply implement NOS activities, but must create a classroom environment that reflects the norms and values of science. For this reason, we hypothesize that an inquiry orientation and the ability to teach science as inquiry may be prerequisite to teaching NOS.

Our second research question was concerned with the ways in which teachers made judgments about the effectiveness of their instruction and its impact on students' views of NOS. While teachers implemented explicit-and-reflective strategies for *teaching* their students about NOS, it became clear during our secondary analysis of the data that they did not implement strategies for formally *assessing* students' ideas of NOS. Teachers' comments about the difficulty of assessing their students' views of NOS allude to a lack of knowledge of summative assessment strategies for NOS. This finding is significant, because teachers' knowledge of strategies for assessing their students' views of NOS can arguably limit the degree to which they can evaluate their own effectiveness in helping students develop appropriate understandings. Without this source of feedback, it would be unlikely that they would be able to make continued improvement in their abilities to teach NOS, as well as their ability to address the specific views and difficulties of their students.

It has been reported in several studies that teachers may indeed believe that they are teaching NOS, however they are not doing so explicitly (Akerson & Abd-El-Khalick, 2003; Bartholomew, Osborne, & Ratcliffe, 2004; Schwartz & Lederman, 2002). The perception of the teachers in these studies was based on what they were doing, not what students were learning as a result of what they were doing. Given teachers' tendencies to indicate they are teaching NOS despite a lack of explicit emphasis within their instruction, it stands to reason that well-designed classroom assessments could provide them with the necessary evidence to determine whether their students are learning NOS. As Schwartz and Lederman emphasize, “student achievement

may and should then affect the teacher and subsequent actions” (2002). Additionally, prior work (Hanuscin, Akerson, & Phillipson-Mower, 2006) suggests that examining students’ views of NOS can be a powerful tool to help instructors further clarify their own understanding of NOS.

We acknowledge, however, that though teachers had readily adapted an inquiry-orientation and implemented inquiry-based instruction consistent with the *Standards*, they continued to struggle with assessment more generally. Because they were teaching science in new ways, they felt uncomfortable using traditional assessment and had to develop new ways to assess their students that were consistent with their instruction. Arguably, they lacked PCK for assessing science, more generally, and thus it is not surprising they lacked PCK for assessing NOS.

Implications

Teacher Education

We believe that teacher education needs to focus on helping teachers embed NOS instruction into their current science units. Teachers may search for already developed activities that have a NOS focus, but it is far better for them to be able to embed NOS in all science content as part of their instructional practice. Based on our findings, we recommend that teacher education and professional development for NOS provide (1) instruction targeted toward improving teachers’ own understanding of NOS; (2) scaffolded opportunities for teachers to implement existing NOS lessons and activities, adapt these activities to their teaching context, and finally develop novel strategies for teaching students about NOS; (3) opportunities for teachers to learn, implement, and develop strategies for both informally and formally assessing their students’ understanding of NOS; and (4) opportunities for teachers use assessment data to reflect on and improve their instruction.

Furthermore, we reiterate that the impact of teachers’ instruction on their students’ views of NOS *must* be considered in evaluating the effectiveness of that instruction—by both researchers *and* teachers. Knowledge of assessment strategies forms an important component of teachers’ PCK and provides crucial information to teachers about the effectiveness of their teaching, which in turn allows them to adjust and respond to students’ understanding. The *National Science Teachers Association Standards for Science Teacher Preparation* (NSTA, 2003) emphasizes that teachers should use assessment to guide and modify instruction. Furthermore, they should be able to “demonstrate that they are effective by successfully engaging students in the study of the nature of science” and that “assessments of effectiveness must include at least some demonstrably positive student outcomes” (NSTA, 2003, p. 17).

Research & Theory

The research conducted, to date, informs us that the process of developing PCK for NOS will take time, just as it does with any other content area. It may be that it seems to take longer than traditional science content, but in fact, most elementary teachers have not heard of the “nature of science” and harbor many misconceptions regarding science as a way of knowing (McComas, 1999). We must first take the time to help teachers confront their misconceptions, develop new ideas, embrace those ideas, design lessons to be able to teach NOS to children, and be able to assess their students’ understandings of NOS and adjust their instructional practices accordingly. This process is necessarily long because there are so many pieces of the puzzle. Accordingly, studies that examine teachers’ development of PCK for NOS over the long term (rather than

during a single course or limited professional development experience) provide the greatest potential to shed light on this complex process.

Proposed models of PCK for NOS emphasize developing the necessary “knowledge, beliefs, intentions, pedagogical skills... that enable a teacher to address NOS within his or her everyday science instruction in a manner... that weaves NOS with other science subject matter (Schwartz & Lederman, 2002, p. 230). Rather than viewing PCK for NOS as distinct from PCK for teaching other science topics, however, we find Magnusson et al.’s model useful in illuminating the challenges and successes faced by our teachers in transforming their understandings of NOS into forms accessible to their elementary students.

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