Critical Incidents in the Development of Pedagogical Content Knowledge for Teaching the Nature of Science: Insights from a Mentor-Mentee Relationship

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Abstract

While teacher educators have had some success in helping prospective teachers understand the nature of science (NOS), they have been less effective in helping prospective teachers *teach* NOS. Though several studies have alluded to impacts of various interventions on developing pedagogical content knowledge (PCK) for NOS, the nature, source, and development of PCK for NOS has not yet been investigated in any systematic way. This study attempts to address that gap by using a self study approach to identify critical incidents in the development of PCK for NOS of both a prospective teacher and science teacher educator. Analysis of data collected over a two-year period during their mentor-mentee relationship illuminates pedagogical dilemmas faced by the prospective teacher in enacting NOS instruction within a school culture of primarily "traditional" science teaching. A series of narrative vignettes are used to illustrate the way in which teaching NOS might be construed as "acts of rebellion," and the ways in which personal convictions and PCK interact. Interpretation of the vignettes from the perspective of the science teacher educator allows for reflection and self-study in regard to preparing teachers to teach NOS. Implications for fostering the development of PCK for NOS within teacher education are discussed.

Introduction

U.S. science education reforms recommend K-12 students develop an understanding of nature of science (NOS). This is distinct from understanding *scientific concepts*, and instead refers to:

> [Understanding] how the body of public knowledge called science has been established and is added to; what our grounds are for considering it reliable knowledge; how the agreement which characterizes much of science is maintained…. the social organization and practices of science, whereby knowledge claims are 'transmuted' into public knowledge, and the influence of science on the wider culture, and vice versa (Driver, Leach, Millar, & Scott, 1996, p. 13).

The authors further emphasize that understanding NOS helps individuals become informed consumers of scientific information, make sense of socio-scientific issues, participate in decision-making processes, and appreciate science as a part of contemporary culture. It should be noted , however, that reform documents such as the *National Science Education Standards* (NRC, 1996) provide a simplified and noncontroversial account of what remains an area of much disagreement and debate among historians, philosophers, and sociologists of science (Duschl, 1994). Despite this, there is some degree of consensus regarding the importance of these ideas about science for science education (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). Seven aspects of the nature of science common to science education 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. Though these are ideas *students* are expected to learn about NOS, research shows that many *teachers* do not adequately understand NOS (Abd-El-Khalick & Lederman, 2000).

While teacher educators have made some progress in helping teachers improve their understanding of NOS (e.g., Akerson, Abd-El-Khalick, & Lederman, 2000; Gess-Newsome, 2002) they have been less successful in helping teachers *teach NOS*. Even when teachers have understandings of NOS consistent with reforms, they generally do not explicitly teach these ideas, or may do so through didactic approaches (Schwartz & Lederman, 2002). Abd-El-Khalick and Lederman (2000) stress that in addition to understanding NOS, teachers need:

> …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)

That is, they require what Shulman (1987) refers to as *pedagogical content knowledge* (PCK) for NOS.

Pedagogical Content Knowledge

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).

Shulman's model has been elaborated upon and extended by other scholars (e.g.Grossman, 1990; Magnusson, Krajcik, & Borko, 1999). As van Driel, Verloop, and de Vos point out, while there is no universally accepted conceptualization of PCK, there is agreement with two key elements of Shulman's model—knowledge of representations of subject matter and understanding of specific learning difficulties and student conceptions (1998). Additionally, they emphasize there is some consensus on the nature of PCK. First, that it refers to particular topics, and therefore is distinct from general knowledge of pedagogy, educational purposes, or learner characteristics; second, that it differs from subject matter knowledge; and third, that PCK is developed through an integrative process rooted in teachers' classroom practice.

Grossman (1990) viewed PCK as being the integration of several knowledge bases including subject matter knowledge (SMK), general pedagogical knowledge (PK), and contextual knowledge (CK). PCK can be generated and developed through (a) observation of classes whether as a student or student teacher; (b) disciplinary education; (c) teacher education coursework; and (d) classroom teaching experience. Gess-Newsome (1999) contrasted this *integrative* model, in which PCK requires flexibly drawing upon these various knowledge bases, with a *transformative* model, in which PCK represents the synthesis of different types of teacher knowledge. In this model, PCK is more powerful than its constituent parts. Magnusson, Krajcik, and Borko's (1999) transformative model of PCK includes five interacting 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., activities for teaching photosynthesis; as well as subject-specific strategies, e.g., inquiry).

PCK for NOS

Within the various domains of teacher knowledge, NOS can be considered part of teachers' subject matter knowledge (SMK)—more specifically, their syntactic knowledge of science, which includes knowledge of the source and justification of scientific knowledge. However, NOS may also be viewed as a particular *topic* within the domain of science. Researchers have argued NOS be viewed as a cognitive, rather than affective outcome of instruction (Abd-El-Khalick, 2001) and that NOS is as much an aspect of subject matter as the reactions of photosynthesis (Lederman, 1998). This is further evidenced by the inclusion of NOS in the content standards in the *National Science Education Standards* (NRC, 1996). Thus, while teachers' own views of NOS are part of their subject matter knowledge, NOS can also be viewed as analogous to other content a teacher might teach, and be considered a topic for which they would develop PCK. For example, according to Magnusson et al.'s model, teachers' PCK for NOS would include knowledge of student misconceptions about the nature of science and of instructional strategies (e.g., explicit-and-reflective instruction) to address those ideas.

Despite 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). 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 in which knowledge of NOS, knowledge of science subject matter, and knowledge of pedagogy blend to form PCK for NOS. Other researchers 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).

We address this gap in the literature by articulating and examining PCK for NOS in relation to existing models of PCK. Through self-study conducted by a mentor (science educator) and mentee (preservice teacher), we identify a series of critical incidents in the development of our PCK for NOS. Currently, "studies of PCK that examine teacher knowledge at critical junctures in a teachers' career are lacking" (Abell, 2008, p. 1411). By more closely examining the transition from the elementary science methods course to the student teaching experience, we hope to shed light on the interplay between the components of PCK and how these explain Jane's initial efforts to teach NOS. Specifically, we ask:

1. What are the nature and significance of critical incidents to the development of a prospective teacher's PCK for NOS?
2. What do these incidents indicate about the interplay between the various components of PCK?
3. How can these be used to inform a teacher educators' PCK in terms of fostering prospective teachers' PCK for NOS?

This investigation provides a unique window into the experiences of prospective teachers following their learning in science methods courses, a view not often available to teacher educators, and we further clarify the problems of practice prospective teachers encounter in transforming their ideas about NOS into forms accessible to students.

Context of the Study

The mentoring relationship between a preservice elementary teacher (Jane) and science educator (Dr. Hanuscin) serves as the context of our study. Jane was enrolled in a master's program, and was obtaining post-baccalaureate certification to teach at the elementary level when she enrolled in Dr. Hanuscin's elementary science methods course. Dr. Hanuscin (Dr. H, as Jane refers to her), is herself a former elementary teacher. She has provided professional development to classroom teachers for the past 14 years, and has been teaching prospective elementary teachers for ten years.

Following Dr. H's elementary science methods course, Jane indicated a desire to gain more experience teaching science, and was invited by Dr. H to co-facilitate a summer science outreach program for elementary students through an independent study. Their mentor-mentee relationship continued throughout Jane's year-long student teaching experience. During this time, Dr. H served as a support system—someone with whom to share problems or questions. Dr. H served as a "safe" person to use as a sounding board and discuss difficulties, as she was not in an evaluative position. Many of their conversations focused on teaching the nature of science, which was a primary focus of Dr. H's elementary science methods course.

The value of mentoring is not limited to new teachers; experienced teachers also benefit by serving as mentors through increasing their awareness of their own professional development and developing a clearer justification for their own teaching practices (Odell, 1990). Thus the mentor-mentee relationship between Jane and Dr. H was mutually beneficial; deepening the Jane's PCK for NOS as well as Dr. H's understanding of how to support prospective teachers in developing PCK for 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).

Methodology

The research relied on self-study (Loughran, 2005, 2007), a method that draws from and builds upon the traditions of reflective practice, action research, and practitioner research. According to LaBoskey (2004), self-study is (a) improvement-aimed; that is, it involves evaluating practice and reframing thinking; (2) interactive; in that it involves engaging with colleagues, students, the literature, and one's previous work to confirm and challenge one's thinking; (3) reliant on multiple, primarily qualitative data sources; and (4) revolves around a need to formalize one's work and make it available to the professional community. As a form of case study, the results of self-study are not intended to be generalized across populations. Nonetheless, this form of inquiry provides in-depth descriptions that illuminate the complexities of teaching and articulate the "wisdom of practice" (Shulman, 2004); consistent with PCK as a theoretical framework. Self-study not only helps those engaged in this type of scholarly activity address problems in their own immediate teaching contexts, but can produce knowledge that "teacher educators in other settings can draw on and adapt to their own teacher education settings" (Dinkelman, 2003, p. 11).

We attempted to capture our PCK in action as well as reflection (Abell, 2007), and consistent with self-study methodology, we utilized multiple data sources. These included (1) lesson plans and instructional materials utilized by both the teacher educator and preservice teacher in their respective contexts, (2) ongoing email correspondence between mentor and mentee, (3) transcripts from semi-structured interviews and collegial conversations in which mentor and mentee discussed problems of practice related to teaching NOS, (4) reflective journals kept by mentor and mentee, (5) articulation of the mentor and mentee's views of the nature of science utilizing the VNOS-C (Lederman et al., 2002), and (6) articulation of the mentor and mentee's PCK for NOS using the Content Representation Tool (CoRe) (Loughran, Mulhall, & Berry, 2006) at four points during the mentorship.

Data analysis was directed toward identifying critical incidents in the development of Jane's PCK for teaching NOS, and examining these in terms of their relation to the various components of PCK. The term "critical incidents" is used to signify turning points or changes in a person or social phenomenon (Tripp, 1993). According to Angelides (2001), it is the justification, significance, or meaning give to these incidents that makes them "critical"—rather than any drama or sensationalism. In teacher education contexts, critical vignettes have been used to promote reflective practice and pedagogical reasoning (Tripp, 1993). In the context of educational research, critical incidents can be documented through personal narrative vignettes, and serve as trustworthy sources of data representing the reality of the participants (Howitt & Venville, 2008). The use of critical incident vignettes is consistent with self-study, which often communicates findings through *assertions* about fundamental aspects of teaching in ways that are identifiable and useful to others, *axioms* that communicate personal beliefs and how those are linked to changes in practice, or *tensions* that make explicit the often tacit knowledge for teaching and thereby help conceptualize the problematic nature of practice (Loughran, 2005).

Ongoing review of the data allowed for us to note particular comments, episodes, and ideas that were foregrounded or referenced repeatedly over time in Jane's experiences. Through this process, a series of potential "critical incidents" were identified. These were selected by Jane, in order to reflect what she deemed to be formative experiences in her developing PCK for NOS. Semi-structured interviews were utilized to probe Jane's thinking further on these incidents, and to determine their significance from her perspective. Together, mentor and mentee narrowed the list to four, representing different experiences and contexts in which Jane developed her PCK for NOS. For each of the selected incidents, Jane prepared a narrative vignette. Several rounds of revision followed, with Dr. H and Jane discussing and clarifying her meaning. This iterative process of co-constructing and interpreting the vignettes proved an opportunity for increased reflection, growth, and change in the way both mentor and mentee perceived their practice.

Completed vignettes were then examined by Dr. H to identify major and minor themes. Triangulation of the vignettes with other data sources, as well as member-checking with Jane, allowed for interpretation of their significance in relation to the various components of PCK. As emphasized by Nilsson (2008), one limitation of examining data in relation to separate knowledge bases, such as those identified by Magnusson et al. (1999) is that these different types of knowledge interact with each other in highly complex ways in the act of teaching, as illustrated in Jane's vignettes. "Hence a difficulty in analysis is in seeking to interpret the data according to the most dominant feature of an incident whilst acknowledging that it may not necessarily be that knowledge alone" (Nilsson, 2008, p. 1288). Accordingly, analysis was also directed toward understanding the interaction of these knowledge bases with one another in relation to Jane's developing PCK.

Findings

The four narrative vignettes in this section constitute Jane's perceptions of critical incidents in her development of PCK for NOS. Each vignette is followed by an interpretation and analysis from the perspective of her mentor, Dr. H. Thus, taken together, these also represent the development of Dr. H's understanding of how to support prospective teachers in developing PCK for NOS. Table 1 provides a synopsis of each vignette, the foregrounded component(s) of PCK, and relevant themes. They are ordered chronologically, beginning with a formative experience in Dr. H's elementary science course, transitioning to a summer teaching experience, and finally Jane's year-long student teaching experience.

Jane's Vignette: *White Men in Lab Coats?*

Being married to an avian ecologist, I know my thoughts about scientists are very unlike other people's ideas. However, I was unaware at just how different my views were until I took my science methods course. The first day of the elementary science methods class, we were asked to draw a picture of a scientist doing science. As I pulled out the markers to draw my scientist in the middle of the woods at a mist net banding a bird, I didn't realize just how unique my drawing would be. When we held up our pictures to show our interpretations, I almost laughed out loud. Every single one of my peers had drawn the same picture! Each of their pictures had a man with crazy hair, glasses, a white lab coat, holding a beaker and inside a room with "scientific" looking tools. I was amazed that I was the only one who

Table 1. Critical Incidents in Developing PCK for NOS

#	Vignette/Synopsis	Elements of PCK	Major theme(s)	Minor theme(s)
1	*White men in lab coats?* Following a "draw a scientist" activity in her methods course, Jane realizes how others view science, and resolves to address misperceptions among her students. At this point, she formulates a rationale for teaching NOS.	Orientation toward science teaching	Portraying science as a human endeavor Developing a rationale for teaching NOS	Making science accessible to diverse learners
2	*Just like a scientist…* Jane confronts a difficult moment while teaching a summer science program, but with the help of her mentor avoids "falling back" on ways to teach science that are easier, but that she feels misrepresent the nature of science. Jane makes a commitment to epistemological consistency between her ideas about NOS and her teaching.	Knowledge of instructional strategies; Knowledge of learners	Teaching science as inquiry Empowering students	Persistence of teacher and student
3	*When experiments don't "work"* During student teaching, Jane recognizes the same misconception among her students that she encountered while teaching the summer program. Since she is attune to this, it becomes a teachable moment where she explicitly establishes norms of science in her classroom. Her knowledge of learners is developed by collaborating to analyze student ideas about NOS.	Knowledge of learners; Knowledge of assessment	Respect for evidence What constitutes "right" answers in science	Science/ science teaching as non-authoritarian
4	*THE scientific method?* During student teaching, Jane reacts to recognizing a myth perpetuated in her curriculum materials regarding the scientific method- and dares to teach the lesson differently. Jane's experience demonstrates how teaching NOS can be an act of "rebellion" when the mandated curriculum doesn't effectively support NOS instruction.	Knowledge of curriculum; Knowledge of learners	Methods of science vs. THE scientific method Adapting curricula to meet students' needs	Student interest in science; teacher socialization into the school culture

thought of scientists the way that I did. Where were the women? Where was the diversity? Where were the people doing field work outside? Where were the insects, plants, mushrooms, elephant dung, binoculars, salamanders, dolphins, cargo pants, duct tape (for getting ticks off of your body) field guides, prairies, oceans, mountains, deserts, forests…. I could go on and on. Where were they? Sure, many of the scientists I know have labs that they work in, but few of them dress in white lab coats and most of them do the majority of their work in other places besides those labs. It made me realize the importance of teaching my future students that science is so much more than what they may picture. There is so much that science encompasses, and it made me wonder how a room full of thirty 20-25 year olds could have such a narrow view of what science is. Who knew that using some as simple as a drawing was a powerful way to find out what our ideas about science were?

Now, the question is: What can we do to show our students the many different aspects of what science is? How can we help them consider as a career and continue on with all of the wonderful work the scientists of this era have begun? In order for them to even begin them thinking about science in this way, I realized for me, as a teacher, it would be important to help my students change their narrow views of what science is all about. Students of all background, gender, ethnicities, shapes and sizes should have the option of pursuing science as a career! Students need to first realize the many different kinds of science in order to fully realize that there may be a branch they would be interested in. My friends that are scientists influence me to teach children that this is a great career to pursue. I see the importance of science every day as well as how fulfilling of a career it can be. Bringing in guest scientists will help show students how fun science can actually be and how many different opportunities and ways there are to become a scientist. I believe seeing real examples will help lead them in the direction of looking further into science as a career.

Analysis and Interpretation* of *White Men in Lab Coats?

This particular event marked a critical incident for Jane in that the experience problematized students' ideas about science. She recognized not only that it is important to teach her students about the nature of science (which at this stage she defined as helping students understand what science is) but also established a rationale for teaching NOS. By helping students see science the diversity of science, both in terms of field of study and the individuals within them, her goal was to open up opportunities for them to pursue a career in science. Her recognition that science could be a fulfilling career is closely aligned with the idea espoused in the *National Science Education Standards* that science is a *human endeavor* (NRC, 1996). Interestingly, however, her rationale is not one of the five arguments for teaching NOS (utilitarian, democratic, cultural, moral, and pedagogical) articulated by Driver et al. (1996). Rather, Jane grounded her rationale in principles of social justice—in encouraging *all* students view science as an endeavor in which they could participate—specifically, in terms of pursuing a career in science. This constituted her orientation toward science teaching, as it reflected what she believed to be her central goal in teaching science, and what served to guide her decision-making about what to teach and how.

Jane's orientation was compatible with teaching about the nature of science. However, not all prospective teachers have the kind of firsthand experiences with science that Jane did, having a husband and friends who were scientists. Rather, they often have misconceptions about the nature of science. Jane's familiarity with scientific inquiry is a tremendous asset to developing PCK for NOS. However; as we see in the next vignette, even when prospective teachers have well-developed beliefs about the nature of science (SMK), they may still find difficulty in enacting classroom practices (PK) that reflect these beliefs.

Jane's Vignette*: Just Like Scientists…*

> *WOW! Today was AMAZING! I have never really seen children as engaged as they are during this science camp. I mean, even the kids who are less engaged are really happy and want to learn and work!*

During the summer, I had the chance to co-teach a science camp for elementary-age kids with Dr. H. I wrote this journal entry the day our students were coming up with ideas about how to test the strength of a magnet. One little boy, Justin, decided that he was going to try to test the strength of magnets based on the force of repulsion; however, this was a very hard thing for him to figure out how to test… he didn't seem to think what he was doing was really giving him a good idea of how strong the magnets were. I tried working with him for a long time, and both of us were getting frustrated. I decided to resort to asking Dr. H to help us solve the situation. I walked over to where she was working with her group of students. Instead of intervening directly and giving the help I thought I needed, she asked me to think back to the way that scientists work. *Do they always have experiments that work as planned? Do they have to try again and again to get a working experiment? Besides, if this method isn't an accurate indication of strength, wasn't it cool that Justin discovered that? Isn't that still valuable?* As I realized what she was telling me, I figured out a way to pose the problem in a positive way to Justin.

To start, I assured Justin that some scientists take years to develop their experiments, yet he was coming up with one in an hour. I also brought up the fact that during his investigation, he had discovered something new about how magnets repel and figured out that his test couldn't measure strength-- *wasn't that totally cool?* Well, if I could explain the look on his face after I was done talking to him; it would make your heart melt. The smile on his face made me realize why I love teaching so much. He was so proud and happy and from then on, he worked as hard as he could no matter what. He didn't always need to feel like he was getting an answer or that the investigation was going to "work". He just kept right at it without giving up! I think he felt like a real scientist… just the way I would have wanted him to!!!

I know it will be difficult to teach this way—lesson plans in the textbooks I've seen are not typically written out in a way that reflects this idea about the nature of science. Instead, they provide step-by-step directions that are almost guaranteed to produce the desired result. Also, the fact that students may have previously experienced a way of learning science in which there is a DEFINITE answer and SPECIFIC way of performing an experiment may make it difficult for students to understand how science really works. If students have never created their own investigations or done inquiry, they may not have experienced the process of making decisions about what data to collect and what the data mean. Students may think that if scientists get an answer that is unexpected, it is a mistake. Beyond that, students could be afraid of getting the wrong answer or a bad grade. In my opinion, wrestling with ideas is important in every subject. I believe that letting students struggle and think for themselves, instead of getting the answers handed to them, will lead to a deep understanding of the material being taught.

Analysis and Interpretation of Just Like Scientists…

Jane's vignette calls attention to the notion that in order to effectively teach about NOS, classroom activities must reflect the norms and values of science—that is, there must be some level of epistemological consistency between what one explicitly conveys about NOS and what is implicit in one's practice. As Clough emphasizes, "ever present in science content and science teaching are implicit and explicit messages regarding the NOS" (2006, p. 464). Even though a teacher may explicitly communicate one message regarding NOS, counter-productive epistemologies may be implicit in instructional methods or materials (Hammer, 1994). This marked a critical moment for Jane in that she persevered and was able to achieve success. Not only did she feel empowered by the experience, but she was able to empower her student and encourage his own persistence in the face of adversity.

All too often, teachers "stage manage" activities to produce the intended results. Nott and Smith (1995) emphasize that by 'rigging', 'conjuring' teachers conceal the problematic nature of inquiry from students. As Jane recognizes, this can produce misconceptions about how science is done. Had she chosen a different way to respond to Justin's dilemma, she may have reinforced the notion that there is once correct answer or one correct way to do science—in essence, undermining students' respect for evidence. In asking Jane to recall her knowledge about the way science is done, I was encouraging her to use those beliefs to guide her instruction and find consistency between her beliefs and practices.

Nonetheless, what also became clear in analyzing this vignette in relation to other data sources is that Jane initially believed this epistemological consistency was sufficient to help students understand the nature of science. As she wrote in one correspondence:

> I'm not even sure I'd have to be explicit about [the nature of science]—like in summer camp, it was more of an approach or *how* we go about the activities. I don't have to point out—OK guys, now you're going to learn THIS idea about science—it's the way I introduce the activities [that would help them understand NOS]

Confronted with this dilemma, and recognizing Jane lacked knowledge of instructional strategies for teaching NOS, I decided to engage her in analyzing students' ideas about NOS as a way to provide evidence that an implicit approach was not enough to produce the results she desired.

As part of the summer program, we had asked students to answer a "question of the day" about NOS based on those in the *Views of Nature of Science: Form D* (Lederman & Khishfe, 2002). Student responses were recorded in their science journals. Over the next several weeks, we engaged in reading and interpreting students' ideas independently and then meeting to compare our interpretations. Jane later reflected on this experience:

> At first I just was laughing… I thought they were "cute little answers" but now I'm thinking about what they mean and how the connect to each other—and how deep the connections are! It's already kind of changed me… working with you, and I can see how our opinions differ, and I start looking at [kids'] responses in different ways… At first, I felt like a lot of these [ideas about NOS] were things they just picked up on; the way we introduced things… I didn't feel like we needed to be explicit. …I became much more worried about [what they thought] by the end.

Through analyzing student work, Jane developed her knowledge of learners—the conditions required for learning (being explicit) as well as common student ideas about NOS, and how these may serve as barriers to learning. As we see in the next vignette, this further influenced the kind of classroom norms Jane hoped to establish.

Jane's Vignette: When Experiments Don't "Work"

I was observing my supervising teacher teach a lesson about pH in science the other day. Students were testing the pH of different samples of water (muddy, acidic, plain and salty). The samples were kept in plastic baggies, so that evaporation and condensation would occur (modeling the water cycle). Students were asked whether the condensation that formed on the inside of the baggies would have the same pH as the sample. The kids were going to do most of the investigating in small groups, but we were discussing our answers as a whole group. Before they would test each condensation bag, the students would predict what they thought would happen. Before the first test, a little girl said, "So, we know if the pH doesn't change from the water to the condensation, the experiment didn't work." I immediately recalled working with Justin the previous summer, and I couldn't hold my tongue! "Guess what guys?!" I said. "That is the coolest thing about science. Sometimes things won't work out how you expect, but even when they don't, you can find much needed evidence to answer your question. There is nothing that we should forget about or think "doesn't work" in science, we should use all the evidence we can!" I could see the pleasure on the kid's faces and was sure it wouldn't go away just because we didn't get the "right" answer. I felt so proud that I was able to help them see the excitement in <u>any</u> answer they may get in future experiments they do!

Looking back on this, I realize I want my students to understand that answers don't come easily—it's a difficult process of making sense of evidence. Evidence doesn't speak for itself; rather scientists must consider whether the evidence is sufficient to answer their question—and be open to not being able to arrive at an answer if the evidence doesn't support one. I remember how once my husband went out to do field work and none of the birds he was supposed to study showed up—instead of thinking that it didn't work, he had to think about *why* the birds didn't show up. Sometimes you just have to deal with what you get!

If we (mis)lead students to believe there is always an answer, or that one "right answer" is out there, then they're likely to 1) have misconceptions about the nature of science and 2) seek answers versus seek to make sense of evidence. Students can get discouraged if they go through a specific sequence of steps and still do not find the answer that they are looking for. However, if they are flexible with their approach of answering a question, they will be more likely to find an answer or at least other ways of approaching the question if they are not satisfied with their answer.

Many different scientists can study the same question and come up with multiple answers---and that is accepted in science! Much of the "right" answer comes from approaches, beliefs and different research methods. The world embraces multiple different answers because it often brings up even more important questions! Students should be comfortable and confident with anything they find even if it is different from their peers. They do have to understand, however, that they need the proper evidence to back up their claims.

Analysis and Interpretation of When Experiments Don't "Work"

Jane's recognition of this 'teachable moment' was based on her knowledge of learners; that is, common difficulties students have in understanding the nature of science. As Jane and I talked about this student's comment, she connected it to similar ideas expressed by students in the summer program. As she explained:

> I could pick things up easily once I knew what I was looking for… Kids think there's a right or wrong answer to their experiment. Isn't that what they're conditioned to look for in a lot of classrooms? We want them to be paying attention to all the evidence, [so we can] challenge misconceptions if they have them.

Jane viewed it as problematic that many elementary students would rely on their teacher to tell them whether or not their ideas were correct. Just as she recognized science to be nonauthoritarian, she wanted her classroom to be a place in which students would make sense of evidence to draw their own conclusions, rather than relying on her as the authority for confirmation of their "correct" answers. By modeling respect for evidence, she hoped to instill this in her students.

Though she articulates very specific things she expects her students to recognize science in this vignette, prior to this Jane had broached the subject about what she would be expected to teach about NOS. After looking over the state standards, the *National Science Education Standards* (NRC, 1996), *Benchmarks for Science Literacy , (AAAS, 1993),* and *Science for All Americans* (AAAS, 1990) she asked, "I understand there are standards, and why they are important—but why so many? Some seem to have different concepts or focus—how do you pull these apart?"

As our conversations continued, I prompted Jane to be more specific about the ideas <u>she</u> wanted students to learn, and how these connected to her own ideas about NOS. The list she generated reflects not only the major ideas encompassed in the reforms, but also her own subject matter knowledge and values:

- Scientific explanations are based on evidence.
- Scientists use different methods depending on the type of question raised.
- Science is accessible to everyone
- Science is ever-changing.
- Scientists use creativity.
- Science doesn't follow a linear model; there isn't one "scientific method" with steps A, B, C
- There isn't always one "right" answer in science.

As we see in the final vignette, by developing clearly defined goals for her students, Jane was able to critically evaluate the curriculum in relation to these goals.

Jane's Vignette: 'THE' Scientific Method?

As I was planning for science, my supervising teacher handed me a textbook that I was supposed to use for my lesson. As I was reading the lesson through, I noticed that it instructed the teacher to get the students familiar with the "scientific method" in order to better prepare them for a plant experiment they would be taking part in. As I began to think back to my science methods course and all the aspects of science that I knew to be important, I began to realize this would contribute to misconceptions as to what science is. As I approached my host teacher with this thought and told her how surprised I was about the curriculum even mentioning the "scientific method" she asked why. As I responded, I realized just how passionate I was. I said, "Not every scientist follows the scientific method. If we tell kids there is a formula to science, it will seem less appealing, less flexible and as a whole-- a lot more boring. However, if we are able to <u>show</u> students the flexibility, excitement and non-linear approach that many scientists have within their work, then we will better be able to capture their interest, encouraging them to *want* to learn more about science." I knew from then on, no matter what the curriculum threw in my face, I would take the "non-linear" approach and teach science how I felt comfortable teaching it… and what I knew in my heart was best for my students!

Science is much more than variables, test tubes, or equations. It is coming up with a question and being able to find the tools and ways to go about getting an answer to that question. One could go about answering the question by experimenting, but there is also observation, collecting specimens, etc. Students should learn that science is flexible and not mapped out for them. They will then have a better appreciation and interest in science and perhaps pursue it later in life. I believe that showing students there are sometimes multiple ways of going about obtaining an answer will be a powerful tool for the future. If I am able to lead them to believe that there is not one way that I expect them to go about answering a question, they will have more faith and confidence in their answers because they were the ones that came up with them.

Students should understand that everyone does science in their own way as well as follow different steps to get to a particular answer. I want the students to learn that there is not a specific sequence of steps they need to go through all the time… although it is important that they realize that they need enough evidence to support an idea (and sometimes they may have to go through a specific sequence of events to figure out that answer—it is just not likely that it will be the same one for every question). You can't teach this idea if you teach "cookbook" science in which students simply follow directions or procedures rather than being challenged to come up with their own questions, ideas, and methods. Who wants to be told the "right" way of answering a question when you are able and free to do it any way you please???!!! Students should be allowed to see that real scientists don't follow a rule or procedure, but are encouraged to use creativity to come up with their own ways of investigating.

Analysis and Interpretation of 'THE' Scientific Method?

Jane's commitment to social justice still figures prominently in this vignette; however, encouraging students' pursuit of science as a career is less foregrounded. This reflects recognition that science is important to learn whether one wants to be a scientist or not. She ties this to immediate goals she has for students (building confidence in one's abilities as a learner) as well as more long term goals (developing an appreciation for science).

In the previous vignette, Jane referred to her unfamiliarity with curricula that emphasize NOS. Despite her self-professed lack of curricular knowledge, she was nonetheless able to critically evaluate the instructional materials she was provided in terms of her goals for science teaching. Her commitment to epistemological consistently is deepened at this point, as she resolved to rely on her own PCK, rather than follow the textbook. She is guided in this by her belief about learners, and awareness of potential misconceptions that could form as a result of using particular instructional strategies or curriculum materials. By adapting the curriculum materials, she believed she could better support student learning about NOS, as well as encourage their interest in science.

A number of factors have been shown to mediate and constrain the translation of teachers' views 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, lack of confidence in one's own understandings of NOS, and lack of resources and experiences for assessing NOS understandings (Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-Khalick & Lederman, 2000). This particular episode illustrates that teaching NOS can be an act of "rebellion" when the mandated curriculum doesn't effectively support NOS instruction. Jane's decision could have put her at odds with her host teacher; however the rationale she provided was enough to convince her host teacher to allow her to adapt the lesson. New teachers aren't always this fortunate to have this kind of support. Rather than implementing reform-based practices learned in their teacher education programs, new teachers often "adopt ways of thinking and acting that [place] them in harmony with the existing occupational culture" (Schempp, et al., 1993, p.448). In this way, Feiman-Nemser argues, teacher education programs represent only a "weak intervention compared to the influence of teachers' own schooling and their on-the-job experience" (2001, p. 1014).

Jane recognizes the differences between the context of teaching at the elementary school and the context of her teacher education program. Despite her growing confidence, she questions whether she is truly capable of teaching NOS. As she explained in our final interview:

> …you have to have a lot of will power—I mean, what's going to keep me from reverting to the way I was taught science? That would be so comfortable! I wonder, *Do I feel passionate enough?* Isn't that what it all boils down to? *Am I going to have the motivation, organization, and passion to actually teach in this way?* …because that's not what you're used to, that's not the model you had. I only had you for one semester—I had all those other teachers for 13 years.

Her comments make the importance of mentoring more evident in helping her through the transition from teacher preparation and the induction years of teaching.

Learning through Mentoring: Teaching Prospective Teachers to Teach NOS

Just as Jane she developed her PCK for NOS, through mentoring her I simultaneously developed my understanding of how to support prospective teachers in developing PCK for NOS. Specifically, I was able to evaluate my teaching practices in the elementary science methods course in terms of how well they prepared Jane for teaching NOS. At times I found reflection uncomfortable, in that I realized there were instances in which I had failed to draw upon my existing knowledge, but had I done so I could have more effectively addressed Jane's areas of difficulty. As Whitehead (1993; cited in Loughran, 2005) stresses, however, the value of self study lies in helping to resolve such "living contradictions" between one's beliefs and practice. Below, I share assertions about helping prospective teachers learn to teach NOS, and describe how the mentoring experience led to these insights. As emphasized by Loughran (2005), the making of assertions from one's self-study is intended to capture some of the fundamental aspects of teaching in ways that are identifiable and usable by others.

A strong rationale for teaching NOS can enable one to overcome potential barriers to NOS instruction.

My experience mentoring Jane prompted me reflect on my own rationale for teaching NOS, which I found aligns very much with hers. Though I had always been 'successful' in science, I never had a true passion to pursue it. Though it sounds absurd to me now, I once had the idea that everything in science had already been discovered, and could be found in textbooks. I believed that my job as a learner was simply to memorize other people's knowledge. When I became an elementary teacher, things shifted—I realized science was not what I *thought* it was, but rather what I *taught* it was. I found myself becoming more and more passionate about and interested in science as I tried to improve my own knowledge and teaching of science. I felt I was actually *learning science* for the first time by teaching it. At that point, my resolve became firm—I didn't want my own students to walk away with the image of science I had formed in my own schooling. Even though the six other teachers on my grade level team rarely engaged their students in science—sometimes fitting in a lesson so that they could justify assigning report card grades for science, I continued to make science an integral part of my instruction—I believed students *deserved* the opportunity to have science portrayed in a way that helped them understand its importance and relevance to their own lives, and that invited them to critically evaluate information in a scientific way.

This rationale remains the core of my practice today—in that many of the prospective elementary teachers with whom I work are indifferent, at best, toward science. By helping them understand the nature of science, I am inviting them to view science in a new way. I am reminded that Lederman emphasized that teacher educators should focus on "promoting internalization of the view that the nature of science is an important instructional objective that should be considered during the development and implementation of every instructional unit, lesson, and activity" (1999, p. 927). Not only understanding that NOS is an important objective, but formulating a rationale for *why* NOS is important for students to learn is essential. Though the fact that Jane was able to do so is encouraging; however, it also raises the question as to whether her classmates were able to do so as well. *Did I make my own rationale explicit to my students? How did I assist students in forming their own rationales for teaching NOS?* Through my mentoring, I realized that though I understood the importance of my own rationale, I had overlooked the importance of my students forming a rationale of their own.

The ultimate evidence for effectiveness of one's NOS instruction is the impact on students' ideas about NOS.

By guiding Jane through analyzing students' responses to questions about NOS, I developed a deeper awareness of the importance of focusing not only on developing prospective teachers' understanding of NOS, but also on helping them develop an understanding and awareness of students' ideas about NOS. Indeed, I had emphasized this point in relation to a research study I conducted in which undergraduate teaching assistants were learning to teach NOS (Hanuscin, Akerson & Phillipson-Mower, 2006). In this study, I found engaging in discussion of their students' ideas about NOS prompted not only clarification of their own views about NOS, but also their comfort in discoursing about NOS in their laboratory sessions. In reflection, I realized that in my methods course I wasn't engaging students in examining students' ideas about science, but rather had (without conscious intent) limited the focus of my course to their own ideas about science.

As a wise (and somewhat blunt) mentor once told me, "If you'd quit focusing on *yourself* and what *you're* doing, and instead start focusing on your *students* and what *they're* doing, you'd be a much better teacher!!!" Teachers can easily focus on their teaching and lose sight of student learning; that is, the act of teaching itself is viewed as what the teacher is doing, versus a negotiation and interaction between teacher and student. Indeed, by better understanding how my instruction impacted student understanding, I became more responsive in my teaching and more aware of how to adjust my instructional strategies to support student understanding. Working with Jane reminded me that prospective teachers must also make this shift from concern for self to concern for learners.

Originally, Jane did not believe she must be explicit about NOS. Only through analyzing students' ideas from the summer program, and identifying ways in which students' misconceptions had persisted, had she realized a need to make her discourse about NOS more explicit. Though we can present explicit-and-reflective instructional strategies to teachers and emphasize that these are effective methods, as Jane put it, "Ultimately, the kids' ideas are the proof".

Discussion and Implications

The method of self-study allowed both mentor and mentee to deepen their PCK in relation to NOS. Jane's identification of critical incidents enabled her to make explicit this often tacit knowledge for teaching, which allowed her mentor to reflect upon and critique her own practices for supporting Jane's development of PCK for NOS. Below, using Magnusson et al.'s model, we discuss Jane's experiences and the salient features of her PCK, as well as the interplay between components.

Orientations

Volkmann and Zagagcz (2004) suggest that a teacher's fundamental beliefs about the nature of science support certain orientations, and unless their beliefs about the nature of science are challenged, their orientations are likely to remain unchanged. Furthermore, teachers' ideas about the nature of science can serve as a barrier for developing orientations toward science teaching that are consistent with reform-based practices, such as inquiry. In this particular case, Jane's social justice orientation was compatible with her goals for teaching about the nature of science, and shaped her practices in meaningful ways.

Orientations play a role in guiding teachers' decision-making, and therefore to a large extent will influence classroom norms, instructional strategies, and methods of evaluation (Magnusson, Krajcik, and Borko, 1999). For the prospective teacher, his or her incoming orientations similarly serve as a filter—allowing them to embrace some material presented in the methods course, while contributing to their reluctance/resistance to embrace others. The orientations that methods students hold upon entry into their elementary science methods course may not be compatible with teaching NOS. Greater awareness of prospective teachers' orientations can inform efforts to help them develop PCK for NOS.

Knowledge of Instructional Strategies

Magnusson et al. distinguish between subject-specific strategies, which are more general approaches for teaching science, and topic-specific strategies, which include both representations and activities to help students comprehend specific ideas and concepts. For Jane, both of these were important in enabling her to teach NOS. For example, inquiry provided a context in which Jane could find epistemological consistency between her beliefs and practices, and through which she could use topic-specific strategies such as explicit-and-reflective instruction about NOS.

For prospective teachers, developing a repertoire of strategies, approaches, and activities is one of the central tasks of learning to teach (Feiman-Nemser, 2001). Methods students may be unfamiliar with instructional strategies such as inquiry, conceptual change teaching, and the learning cycle. Furthermore, they may not easily adapt to these strategies, either due to their own unfamiliarity and lack of models of these types of instruction, or a perception that such strategies are not well-supported in schools. The latter may be reinforced by their field experiences and student teaching.

Jane's experience is exceptional, in that she was afforded the unique opportunity to participate in inquiry-based instruction during the summer program for students. By experiencing inquiry-in-action, she viewed this method as feasible and achievable. The same may not be true for other prospective teachers, who have not experienced inquiry as learners, nor viewed inquiry being taught in schools. If the school culture does not effectively support NOS, that is, the instructional strategies in use do not provide a context consistent with NOS, it can be especially challenging for prospective teachers to enact NOS instruction. In essence, asking prospective teachers to teach NOS may be asking them to 'rebel' against the prevailing norms and practices within the school in which they are placed.

Knowledge of Learners

In Magnusson et al.'s model for PCK, knowledge of learners consists of two categories of knowledge; that of requirements for learning and that of areas of student difficulty. As Abell (2007) points out, while research has shown that teachers, overall, lack knowledge of students science conceptions, this knowledge improves with teaching experience. Jane's experiences teaching science both in the summer program and her year-long student teaching supports this. As Jane's knowledge of learners grew, she became more conscious of the importance of establishing a classroom environment that reflected the norms and practices of science. Furthermore, she became more attune to interpreting students' comments in light of their implications for NOS.

It is typically assumed that, in comparison to expert teachers, new teachers will be less aware of alternative conceptions (or "misconceptions") students are likely to hold about a topic, as well as specific difficulties they may have with learning particular content. However, when it comes to NOS, this assumption may prove false, particularly given the large body of research that shows teachers typically lack understanding of NOS themselves. In Jane's case, she appeared more the expert than her cooperating teacher when it came to NOS. This point reinforces the importance of focusing on developing prospective teachers' knowledge of learners in relation to NOS within the methods course, as students are not likely to be supported by their mentor teachers in developing this knowledge during their field experiences and student teaching.

Knowledge of Curriculum

Knowledge of curriculum refers to both the goals and objectives for learning, as well as actual curricular materials to support students in meeting these goals and objectives. Though Jane was able to clarify her understanding of reform documents and the ideas about NOS that were important to understand, she remained concerned that none of the curricular materials she knew of addressed these goals in meaningful ways. Schwartz and Lederman, 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). Jane was able to respond to discrepancies between her goals and the textbook materials; however as a new teacher, it is likely that this would be a time-consuming and difficult process if no appropriate materials were available. Appleton (2006) described elementary teachers' desire for ready-to-implement "activities that work" and suggests that, indeed, these may play an important role in the development of elementary teachers' PCK for teaching science. It seems likely that exemplar NOS lessons and activities might provide a scaffold for Jane in developing her PCK. Nonetheless, there are currently few examples of curriculum materials that effectively address NOS at the elementary level, further underscoring a need for educative curriculum materials that can support teachers in developing PCK for NOS (Hanuscin et al., 2008).

Knowledge of Assessment

Like her knowledge of curriculum, Jane's knowledge of assessment proved to be less developed than other components of her PCK. While she was guided in analyzing student ideas through assessments planned as part of the summer science program, she did not assess students' ideas about NOS in formal ways. A review of the current literature on teaching NOS shows this is not atypical; while there has been much debate among science educators as to the best way to assess understanding of NOS for research purposes, teachers' classroom-based strategies for assessing their students' understanding of NOS has received little, if any, attention in the literature. Indeed, what little information does exist reveals that teachers primarily rely on more informal forms of assessment, such as listening to students' ideas during discussion, to get a sense of what their students are learning about NOS (Bartholomew, Osborne, & Ratcliffe, 2004; Hanuscin, Lee, & Akerson, 2008; Schwartz & Lederman, 2002).

The journal reflections utilized in the summer program were effective in providing Jane with some sense of her students' ideas about NOS, which in turn helped her utilize class discussions to diagnose students' misconceptions about NOS during student teaching. However, if, as Jane emphasizes, the "ultimate proof" of the effectiveness of her instruction is her students' ideas, without sufficient knowledge of assessment, it is likely she would be unable to garner the evidence necessary to evaluate the effectiveness of her instruction. By clarifying her teaching goals for NOS and articulating the ideas she wanted students to learn, she developed her understanding of *what to assess*, but still lacked knowledge of *how* to assess those ideas.

Though there is a general lack of studies on future and beginning teachers' knowledge of assessment, in my experience I find this to be one of the weakest areas of knowledge for methods students. They may lack knowledge of what knowledge and skills are important to assess, and focus instead on criteria such as neatness, completion, or effort to assign grades to student work products. Many will have limited knowledge of assessment strategies, and associate assessment with tests and quizzes, viewing assessment as solely summative in nature. Jane's case highlights the importance of considering prospective teachers' knowledge of assessment with regard to NOS, in particular.

The Interplay between Components of PCK and Knowledge Transformation

Our findings align with prior research by Magnusson et al. (1999) that suggests the development of teachers' PCK may be uneven, in that changes in knowledge of one component (e.g., knowledge of instructional strategies) may not be accompanied by changes in other components (e.g., knowledge of assessment). For example, while Jane developed knowledge of instructional strategies in her methods course, she did not develop her knowledge of learners. As attested to by Magnusson et al. (1999), such lack of coherence between different components can be problematic in enacting PCK. We see this exemplified in Jane's failure to implement explicit-and-reflective strategies, because she did not see these as necessary for students to learn NOS. Only by developing her knowledge of learners and the requirements for learning, did she do so.

Though the mentor-mentee relationship helped strengthen Jane's knowledge of learners, she still had underdeveloped knowledge of curriculum and knowledge of assessment. This finding lends support to the assertion that teacher knowledge builds from more generalized pedagogical knowledge and isolated bits of PCK, and moves toward PCK that is more integrative and transformative (Friedrichsen et al., 2007; Wang & Volkmann, 2007). The complexities of teaching NOS became much more obvious to Jane as she became more aware of the students' ideas. Her knowledge of learners' ideas about NOS transformed the way she viewed curriculum (e.g., as perpetuating students' misconceptions about NOS) as well as the context in which learning occurs (i.e., how students may be 'conditioned' to look for right answers versus exhibit respect for evidence). Jane's experience illustrates how coherence among various components can lead to more meaningful transformations of one's knowledge.

As Magnusson et al. emphasize, the value in PCK as a framework lies in its usefulness to guide both future research and program development.

> Ideally, for a science teacher education program to be comprehensive and coherent, all of these areas should be addressed. However, we recognize the difficulty of that undertaking, and we do not suggest that programs which focus on only a subset of the components cannot be successful. Instead, we caution that teacher educators should be aware of the possibility that teachers may not have requisite knowledge of components not addressed by the program that would help them effectively use the knowledge they develop from the program (1999, p. 126).

As we saw in Jane's case, her knowledge of learners proved requisite to implementing her knowledge of instructional strategies in appropriate ways. Along these lines, one implication of our findings is that in addition to focusing on *instructional strategies,* teacher education programs should help prospective teachers develop the complementary *knowledge of assessment* to enable them to assess the impact of their instruction and gain a greater awareness of students' ideas.

Teachers' ability to assess their students' views of NOS can arguably limit the degree to which they can evaluate their own effectiveness. 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 identify and address the specific views and difficulties of their students. The current body of research focused on teachers' ability to teach NOS (e.g., Abd-El-Khalick & Lederman, 1998; Bartholomew, Osborne, & Ratcliffe, 2004; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2001) has paid little attention to this aspect of PCK. Indeed, like Jane, teachers often believe they are teaching NOS—but are not doing so explicitly (e.g., Schwartz & Lederman, 2002). It stands to reason that well-designed assessments could provide teachers with evidence that can problematize this assumption, and inform their subsequent actions. Further research is needed to test this assumption and more clearly examine the interplay between various components of teachers' PCK for NOS.

Furthermore, we argue that the PCK framework may lead to a richer understanding of why teachers may fail to enact particular practices. For example, 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). What led to this discrepancy? When viewed from a PCK perspective, we are encouraged to consider whether or not these prospective teachers possessed the necessary knowledge of what to assess in relation to NOS and how to assess it.

It is assumed that PCK usually develops over an extended period of time teaching a topic; nonetheless, our research suggests that studies focused on preservice teachers' PCK are of value in terms of better understanding the *process* through which PCK develops. Understanding the interplay between various components of PCK, and specifically whether some serve as requisite to developing other components of PCK can support teacher educators in designing instruction to better foster teachers' PCK.

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