A Developmental Continuum of Pedagogical Content Knowledge for Nature of Science Instruction

Byoung S. Kim
kimbyou@iit.edu

Eun K. Ko
koeunky@iit.edu

Norman G. Lederman
ledermann@iit.edu

Judith S. Lederman
ledermanj@iit.edu

Department of Mathematics and Science Education
Illinois Institute of Technology
Chicago, IL 60616

Abstract

The purpose of this study was to examine how K-12 science teachers incorporated aspects of nature of science (NOS) within their lessons. The present study was conducted in the context of a professional development program called Project ICAN: Inquiry, Context, and Nature of Science. Fifty-nine K-12 science teachers participated in Project ICAN. During Project ICAN, three microteaching lessons were assigned to the ICAN teachers. Lesson plans for lessons, videotapes of lessons, observation notes during lessons, and informal interview notes were analyzed to find how teachers changed their pedagogical approaches for NOS and how they addressed aspects of NOS through three microteaching sessions. The data analyses indicate that there are two critical changes that need to occur in order to implement explicit and reflective NOS instruction. Teachers need to realize that explicit is better than implicit instruction. Then, they need to be aware that a student-centered approach to explicit and reflective is better than a didactic approach. The ICAN teachers’ NOS knowledge, NOS-specific pedagogical knowledge, and subject matter knowledge played a role for NOS instruction.

Paper Presented at the Annual Meeting of the National Association for Research in Science Teaching, Dallas, Texas. April 4-7, 2005.
Nature of science (NOS) has been a common theme in science education reform efforts as an essential aspect of scientific literacy (e.g., American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996). In light of efforts to improve students’ understanding of NOS, recent research has focused on equipping pre- and in-service teachers with an adequate understanding of NOS (e.g., Akerson, Abd-El-Khalick, & Lederman, 2000; Shapiro, 1996).

However, the discrepancy between a teacher’s understanding of NOS and classroom practice has been consistently noted (e.g., Abd-El-Khalick, Bell, & Lederman, 1998; Brickhouse, 1990; Lederman, 1999). The assumption that teachers’ knowledge of NOS is directly and necessarily conveyed to their students through classroom teaching lacks empirical support. Teachers’ understandings of NOS appear to be essential, but not sufficient, for translating their understandings into science teaching. Teachers who have an understanding of NOS consistent with reform documents (AAA, 1993; NRC, 1996) generally do not attempt to teach any aspects of NOS explicitly or adopt inappropriate approaches for teaching NOS (e.g., didactic approaches). The lists of constraints that potentially impede teaching of NOS have been documented in recent literature (e.g., Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001). Those constraints, in general, can be divided into two groups. One group includes factors that inhibit teachers’ initiation of NOS instruction such as pressure to cover content (Duschl & Wright, 1989; Hodson, 1993), perception of NOS as less significant than other cognitive outcomes such as science content and processes (Abd-El-Khalick et al., 1998), and instructional intention to teach NOS (Lederman, 1999). The other consists of factors that impede explicit and reflective NOS instruction, such as confusion between NOS and science processes and lack of knowledge related to pedagogical approaches for NOS (Abd-El-Khalick, 1998) and lack of subject matter knowledge (Schwartz and Lederman, 2002).

One of the factors that facilitates or impedes teaching of NOS is knowledge of NOS-specific pedagogical approaches. Although a teacher may have an adequate understanding of NOS, knowledge of how to teach NOS is necessarily required for the translation of this knowledge into classroom practice (Akerson & Abd-El-Khalick, 2003; Schwartz & Lederman, 2002). However, pedagogical knowledge of how to explicitly and reflectively address NOS in classroom practice
has not been the main focus of much research. Indeed, the majority of research on helping teachers’ pedagogical knowledge for NOS has been conducted in the context of preservice education and not with inservice teachers. The present study focused on K-12 science teachers’ pedagogical knowledge related to NOS in the context of a professional development program.

Pedagogical approaches for NOS

In general, NOS-specific pedagogical approaches can be categorized into either implicit or explicit and reflective. The implicit approach proposes that by engaging learners in inquiry-based activities, or exposing learners to episodes of history of science, they will also come to understand NOS. With respect to an inquiry-based approach, it is assumed that learners may be able to understand epistemological meanings behind “doing science”. For example, through experiences of generating data, using those data to explain certain problems, and comparing their explanations with a scientific theory, learners are expected to develop an understanding of how scientific theories change (Sandoval & Morrison, 2003). Research adopting this approach has provided little evidence for its effectiveness on learning of NOS (Khishfe & Abd-El-Khalick, 2002; Meichtry, 1992; Moss, Abrams, & Kull, 1998; Moss, Abrams, & Robb, 2001; Sandoval & Morrison, 2003). The historical approach suggests the incorporation of history of science in science teaching is essential in order for learners to enhance their understandings of NOS. History of science has been viewed as having a significant role in learning NOS. The approach assumes that learners will discern aspects of NOS embedded in historical episodes. Evidence concerning the effectiveness of the historical approach (Abd-El-Khalick, & Lederman, 2000; Solomon, Duveen, Schot, & McCarthy, 1992) is, at best, inconclusive. Therefore, research using an implicit approach indicates that it is unlikely that learners can learn what teachers do not intentionally teach by simply engaging in inquiry-based activities or historical episodes.

The explicit approach recommends that the goal of improving learners’ views of NOS ‘should be planned for instead of being anticipated as a side effect or secondary product’ of varying approaches to science teaching (Akindehin, 1988, p. 73). Like any other cognitive learning outcome, NOS should be specific and tangible content that teachers intentionally plan to teach and assess in classroom instruction. Recent reform documents also have advocated NOS as ‘content’ that K-12 students should possess for scientific literacy (AAAS, 1993; NRC, 1996). It should be noted that the explicit approach does not refer to a didactic strategy. Rather, the
explicit approach to instruction is comprised of NOS-relevant questioning, discussions, and guided reflection to help learners understand target aspects of NOS. Therefore, in this study the authors use an ‘explicit and reflective’ approach to distinguish from an explicit but not reflective teaching. Empirical support has been obtained for the effectiveness of the explicit and reflective approach in enhancing learners’ understanding of NOS (e.g., Akerson, Abd-El-Khalick, & Lederman, 2000; Akindehin, 1988; Khishfe & Abd-El-Khalick, 2002; Ryder, Leach, & Driver, 1999).

Empirical results on implicit versus explicit and reflective approaches indicate that knowledge of general pedagogical approaches (e.g., inquiry-based and historical approaches) is not sufficient to address NOS in classroom practice, even if those approaches can be successfully adopted in teaching other subject matter knowledge, such as process skills and science content (we believe that NOS is also science subject matter, but for convenience of discussion, we separate NOS from subject matter knowledge and in fact, researchers have separated NOS from subject matter knowledge either). Suffice it to say, teachers need NOS-specific pedagogical knowledge to integrate NOS into science lessons in order to convey NOS to learners in an explicit and reflective manner.

**Improving teachers’ pedagogical approaches for NOS**

Recent research on improving teachers’ abilities to teach NOS has been carried out mostly with preservice teachers. Abd-El-Khalick, Bell, and Lederman (1998) investigated the relationship between preservice teachers’ understanding and their teaching of NOS. Spanning two semesters, two science methods courses, a science pedagogy course, and a science field-based internship heavily emphasized NOS and how to teach NOS. During the following semester, participants completed a full-time internship in a school setting. Participants’ understandings of NOS assessed at the end of coursework were compared with their teaching practice in the student teaching internship. The data analyses showed that participants possessed adequate understandings of NOS, but few explicitly addressed NOS in their teaching. Although many participants claimed that they taught NOS, their pedagogical approach to teaching NOS was simply to involve students in doing science without any attempt to discuss about NOS. They did not recognize their implicit teaching which was not very effective.
In a follow-up study, Bell, Lederman, and Abd-El-Khalick (2000) hypothesized that the lack of preservice teachers’ pedagogical knowledge for teaching NOS might be caused by the simultaneous exposure of preservice teachers to learning NOS and how to teach NOS in methods courses. Therefore, the intervention was to separate teaching NOS from instruction on how to teach NOS to secondary students. The results indicated that participants were better than those in the prior research with respect to the teaching of NOS in an explicit and reflective manner. The participants in the study taught NOS more frequently in the student teaching internship and knew the importance of explicit and reflective instruction. However, the majority neither included NOS objectives in their lessons nor attempted to assess students’ understandings of NOS.

In integrating NOS with science lessons, teachers’ subject matter knowledge appears to be an important factor. In a case study conducted by Schwartz and Lederman (2002) the perservice teacher Rich, who had an extensive science background was better able to implement NOS instruction than the other participant with limited subject matter knowledge. However, Rich also had difficulty fitting NOS into the context of unfamiliar science content, even though he was successful in integrating explicit and reflective NOS teaching into familiar science content teaching.

A similar pattern regarding the role of subject matter knowledge was found in the study by Akerson and Abd-El-Khalick (2003), which was conducted with an inservice elementary teacher. The data analyses indicated that one teacher, Tina, held informed views of NOS and strong intent to teach NOS in her lessons. However, her teaching of NOS was initially restricted to implicit approaches of just involving students in activities of “doing science” without any debriefing related to NOS. In content-specific lessons (e.g., a model of the inside of the earth), she could not address NOS in the lessons because she lacked the necessary content knowledge. Since she did not know what the evidence is for the model of the inside of the earth, she could not highlight the fact that scientists could not see the inside of the earth, so they needed to infer and develop a model of that based on collected data. With several supports including model lessons by the researchers, Tina was able to use explicit approaches for NOS.

The existing literature implies that science educators should specifically help teachers learn how to teach NOS. The efforts include helping teachers shift their pedagogical approaches of teaching NOS from implicit to explicit and reflective, learn how to assess their students’ understandings of NOS, and improve their abilities to fit NOS into science content lessons. In
establishing in-depth knowledge of how to help teachers develop knowledge in NOS instruction, some work is still left to be done. First, most research on enhancing teachers’ NOS instruction has been done with preservice teachers. More empirical research is needed with inservice teachers, since experienced teachers are different from preservice teachers in pedagogical and subject matter knowledge. It is still unknown whether general findings about teaching NOS with preservice teachers would be similarly shown in the context of inservice teachers’ NOS instruction. Second, it is essential that we examine the ways teachers fit NOS into their lessons. Little research has been conducted on what lesson contexts teachers feel comfortable to address NOS and in what contexts they do not.

The present study focused on helping inservice teachers improve their pedagogical knowledge for teaching NOS through a professional development program. Teachers’ change in pedagogical knowledge for NOS was assessed through microteaching practice given as an assignment three times during the professional development program. The teachers’ general manner of addressing NOS in their microteaching presentations was investigated as well as their improvement. The research questions guiding the present investigation were:

1. How do teachers generally address NOS in their microteaching lessons?
2. Do teachers improve their pedagogical knowledge related to NOS through their microteaching lessons?

Nature of Science

Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) emphasized several aspects of NOS that are accessible to K-12 students and relevant to their daily lives. Central among these aspects is that scientific knowledge is (a) tentative, (b) empirically based, (c) subjective, (d) partly the product of human inference, imagination, and creativity, (e) socially and culturally embedded, and (f) necessarily involves a combination of observation and inferences. An additional consideration is (g) the function and relationship between scientific theories and laws. These seven aspects of NOS were the focus of the current investigation.
Methods

Participants

Fifty nine applicants were selected for the fourth year of Project ICAN. The group represented six science areas including general science, biology, physics, chemistry, earth science and environmental science and spanned grades K-12. During the year-long program, teachers came from 51 different schools throughout the Chicago area, impacting multiple school districts. The teachers were diverse in terms of ethnicity and taught in diverse classrooms.

Context of the Study

The current study was conducted in the context of the fourth year of a project on Inquiry, Context, and Nature of Science (Project ICAN). Project ICAN is a professional development project spanning one year and designed to enhance K-12 science teachers’ knowledge and pedagogical knowledge related to NOS and scientific inquiry (SI). Project ICAN was comprised of four stages: Summer Orientation; Academic Year Activities; Summer Institute; and Science Internship. The third and the fourth researchers provided the professional development to the ICAN teachers, and the first and the second researchers analyzed the data collected from the ICAN teachers.

It should be noted that this present study focused on only NOS even though Project ICAN dealt with NOS and SI both in order to make it easy to clarify NOS-specific knowledge base.

Summer Orientation: In August 2003, year 4 of Project ICAN began with a three-day orientation. The orientation mainly focused on introducing teachers to aspects of NOS and SI by engaging them in NOS and SI activities. Teachers actively participated in 10 NOS and/or SI activities (Lederman & Abd-El-Khalick, 1998; National Academy of Science, 1998), watched relevant videos, and read NOS and SI specific articles. Reflective questions, debriefings, and discussions followed to make teachers familiar with aspects of NOS and SI.

Academic Year Activities: After the orientation, monthly full-day workshops were held from September 2003 through June 2004. These workshops were centered on further NOS and inquiry instruction in the context of science subject matter, curriculum revision, and assessment.
September through November, the ICAN teachers participated in various NOS- and SI-focused activities that were embedded in specific science content or more generic in nature (Lederman & Abd-El-Khalick, 1998). The content-embedded activities included the hanger activity, the mitosis lab activity, and the fossil activity. In the mitosis lab activity (Lederman & Lederman, 2004), for example, the ICAN teachers were provided with two different teaching approaches. First, they were given a brief review of the different stages of mitosis and how to categorize stages from pictures, and then teachers were asked to count the number of onion root tip cells in each stage of mitosis within a given field of view under high power. After the counts were entered on a data table, they used the relative frequencies of stages to calculate the relative time required for each stage. The second approach was that teachers were given the same brief review, but in this time, teachers were asked to answer how we decided when one stage ended and the other began and how scientists determined this. A striking difference was that the first approach involved teachers in doing an investigation, but without any integration of NOS. Unlike the first one, the second engaged in NOS discussions initiated with carefully selected and placed reflective questions, which was followed by addressing certain aspects of NOS such as tentativeness, creativity, observation versus inference, subjectivity, and empirical basis.

An example of a more generic activity was the tube activity (National Academy Science, 1998). Teachers were shown a mystery tube and its behaviors. They were then asked to infer what the structure of the inside of the tube looked like and design and construct physical models that behaved in the same way as the original tube. The NOS discussion focused on elements of NOS, such as how and why inferences were different from observations, how human subjectivity led to different models that replicated the original tube in the same way and inconclusive nature of a scientific model, followed by authentic examples of natural science like models of an atom.

Teachers were also encouraged to apply what they learned through ICAN workshops in their classroom, and to bring their classroom experiences to the following ICAN workshop to share and discuss with each other.

During the academic year, two microteaching lessons were assigned (in January and May 2004), and one more presentation was arranged for the summer institute (in July 2004). As preparation for microteaching, the December monthly workshop provided teachers with sample model lessons from year three ICAN teachers. Teachers were asked to choose a teaching topic
that they had already taught and develop a lesson plan aimed at teaching NOS and SI. In doing so, ICAN staff individually helped and guided each teacher group.

Thirteen teacher groups presented their lessons in January (detailed description will be followed in the microteaching section). The following workshop in February involved teachers in discussions on the difficulties teachers faced in teaching NOS and SI. Another model lesson was presented to help teachers ameliorate the difficulties.

During the March workshop, teachers were involved in activities aimed at integrating technology (e.g., Vernier probes) with NOS and SI instruction. NOS and SI instruction, integrated with technology, was compared and contrasted to traditional teaching approaches using technology. In April, curriculum evaluation and revision in terms of teaching NOS and SI were a focus. Teachers brought their own curriculum materials and were asked to evaluate them and revise some lessons for NOS and SI through the guidance of Project ICAN staff.

The second microteaching lessons by 14 teacher groups were presented in May in the same manner as in January. The following monthly workshop included the discussion of the second microteaching lessons, and how to assess students’ understandings of NOS and SI.

**Summer Institute:** From the end of June to the beginning of July, 2004, a nine-day summer institute took place. The Institute aimed to help the ICAN teachers elaborate their understandings of NOS and SI, and pedagogical knowledge through a series of explicit/reflective activities, readings, and discussions. The previous year ICAN teachers were invited to share their teaching experiences with the current ICAN teachers. Several model lessons teaching NOS and SI were provided by a first year ICAN teacher. The ICAN teachers read the book of E=MC² (Bodanis, 2000) and aspects of NOS and SI embedded in historical episodes in that book were reviewed. A variety of assessment techniques for NOS and SI were introduced and ways to assess students’ understandings of NOS and SI were discussed. In order to help teachers integrate NOS and SI with technology-based instruction, teachers were engaged in several activities using Vernier Probes. At the end of the Summer Institute, teachers presented their final microteaching lessons.

**Science Internship with Research Scientists:** Additionally, during the academic year the ICAN teachers also participated in a science research internship with a practicing scientist on the IIT campus or in surrounding community resources (e.g., zoos, museums). Teachers spent five
hours per month from January through June with mentor scientists. The teachers' primary role was as participant observers. They engaged in various aspects of the ongoing investigations in the research settings, and discussed specific research content and techniques with the scientists. Research areas included were crystallization, vascular tissue engineering, thermal processing of materials, nutrition, biochemistry, molecular biology, microbiology, protein purification and genetics. Teachers kept daily journals, guided by focus questions, that asked teachers to connect their experiences in research settings and aspects of NOS and SI.

**Microteaching**: In this study, microteaching refers to a peer teaching of what teachers plan to do with their students. Teachers were asked to present their lessons as team teaching at monthly meetings in January, May, and July. A teacher group consisted of three to four teachers and teachers were asked to change their groups for each microteaching assignment. Thirteen, 14, and 12 ICAN teacher groups presented their lessons each time. The ICAN teacher groups were split into middle/elementary level (K-8th) and secondary level (9-11th), and thereby presented lessons in two separate rooms. Each lesson was presented within 45 minutes and afterwards there was a brief discussion of each lesson. Additionally, ICAN staff provided written feedback to teachers in terms of how to better integrate NOS and SI with their lessons.

In the present investigation microteaching was used for two purposes. First, it was a tool of assessing the ICAN teachers’ pedagogical knowledge related to NOS. The context of microteaching presentations would be mostly safe from the identified constraints that potentially impede teaching of NOS, such as pressure to cover content, classroom management, and institutional constraints. Since the ICAN teachers were asked to plan and teach NOS in lessons, the voluntary intention to address NOS in science teaching (Lederman, 1999) could not be considered as a factor that affected the ICAN teachers’ microteaching presentations either.

In addition, microteaching assignments were also employed as an intervention along with the entire program of Project ICAN. It provided the ICAN teachers with opportunities to plan NOS lessons and implement their lesson plans, and to observe their peers’ presentations in the context of various science content and teaching approaches. Therefore, any outcomes of the ICAN teachers’ pedagogical knowledge for NOS can be attributed to the impact of microteaching and the rest of the Project ICAN program.
Importantly, it should be noted that microteaching cannot reflect a real classroom situation. There is always the possibility that teachers cannot implement the same teaching demonstrated as in microteaching in their real classroom setting. This fact is a limitation of the present study and should prudently be considered in interpreting the findings.

Data Sources and Collection

The data set included teachers’ plans for their microteaching, videotapes of microteaching lessons, and observation notes that the researchers had taken during microteaching lessons. Thirteen (seven secondary and six middle/elementary) and 14 teacher groups (seven secondary and seven middle/elementary) presented lessons in the first and the second microteaching sessions, respectively. In the final microteaching session 12 teacher groups (six secondary and six middle/elementary) demonstrated lessons. Therefore, a total of 39 teacher groups’ plans and videotaped lessons were collected. Each lesson plan included handouts distributed during the lesson. The first and the third researchers, and the second and the fourth researchers observed the secondary level lessons and the middle/elementary level lessons, respectively, and took observation notes for each lesson.

Indeed, the data set included informal conversation notes. The researchers continuously interacted with teachers talking about NOS and SI while teachers prepared for their lessons, took breaks, and even during lunch time. The important conversations that showed teachers’ ideas about teaching NOS were written down and sometimes were audiotaped.

Data analysis

Data analysis was performed after collecting the data from all three phases. All the data analyses were conducted by the first and second authors.

The researchers independently read lesson plans and observation notes for each of microteaching lessons and summarized them. Then, they watched each video-taped lesson and independently made a qualitative description regarding general teaching sequence, how to address aspects of NOS, and how to assess students’ understanding NOS. With respect to the degree of the attempt to address NOS aspects, after a couple rounds of analyses, the researchers found that all lessons generally fell into one of three levels, Level 1-implicit, Level 2-didactic, and Level 3-explicit and reflective. The researchers agreed on all lessons except three which
were either between Level 1 and Level 2 or between Level 2 and Level 3. Through discussion, the disagreement was resolved. The common features of each Level will be described in the result section.

The change in the frequency of each Level lesson through three microteaching practices was calculated. The movement from Level 1 to Level 2 and to Level 3 was interpreted as the improvement of the ICAN teachers’ pedagogical knowledge of teaching NOS.

Then, the researchers collaboratively developed explanations for why some ICAN teacher groups failed to implement more explicit and reflective NOS instruction. The researchers repeatedly read the written data set and watched the video-taped lessons. Indeed, any NOS-related conversations with students in video-taped lessons and the audio-taped informal conversations with the ICAN teachers were transcribed and used for this analysis. The emergent explanations in specific lessons were checked against other lessons and any disconfirming data were detected and used to revise the initial explanations.

Results

General Ways of Integrating NOS in Each Level

A total of 39 lessons were presented through three microteaching practices. All microteaching lessons avoided expository teaching strategies. Rather, they provided students with demonstrations and engaged them in investigations and making models or group discussions in the context of science content, such as water cohesion, evolution, electricity, magnetism, classification, recycling, and so on. The researchers sorted all lessons into three Levels. First, general characteristics of each Level are described and then, the ICAN teachers’ changes in NOS instruction during the ICAN program. Second, two detected factors that influence the ICAN teachers’ NOS instruction are discussed.

In the following section, each ICAN teacher group is identified by a letter and a number. The letters “G” of Group and “M” of Microteaching are used to identify groups in each microteaching session. The numbers, which run from 1 to 14 in “G” and from 1 to 3 in “M”, identify each group in each microteaching session. For example, G12M2 presents the group number 12 during the second microteaching session in May.
Level 1: Implicit Teaching by Only Doing NOS

From the analysis of 10 Level 1 lessons, the ICAN teachers initially appeared to believe that students would learn NOS by doing science. Pieces of evidence for implicit teaching were detected in lesson plans as well as their microteaching. All lesson plans for those Level 1 lessons included target aspects of NOS, but most of them did not incorporate how to address the target aspects of NOS. Indeed, aspects of NOS were little specified as outcome in their instructional objectives (Bell, Lederman, & Abd-El-Khalick, 2000). The objectives were related to doing science and/or only science content. One middle/elementary group’s example is as follows:

Inquiry and Nature of Science:

- Use data to construct a reasonable investigation
- Plan and conduct a simple investigation
- Tentativeness
- Creativity
- Observation and Inference

Objectives:

Students will be able to…

- Distinguish the difference between attraction and repulsion of poles
- Realize that all metal are not magnetic
- Compare the strengths of two different types of magnets

It seems that the ICAN teachers chose certain aspects of NOS based on what their students would do in their lessons. As an example, the target aspects of NOS and its short description from one lesson plan below indicates that certain aspects of NOS were thought of as what students would do.
Creativity: students have to be creative to uncover all the steps that required the consumption of energy.

Observation vs. Inference: everything in the lesson is observed and the interpretation involves some inferring.

Theories and Laws: The law of conservation of matter and energy will be taught in this lesson.

(G10M2)

This implicit approach shown in lesson plans was consistently identified in microteaching lessons as well. One secondary group used a crushing can demo to explore a relationship between temperature and pressure. Three target aspects of NOS were written down on the lesson plan.

Observations vs. inferences
Subjectivity of possible solutions
Creativity to propose a solution

(G1M1)

In this group’s lesson plan, students were supposed to make observations, develop an explanation for the can demo, and present their explanations. No plan for teaching the target aspects of NOS was found. The teachers appeared to assume that students would learn those three aspects of NOS above through observing, developing an explanation and presenting. Their microteaching was consistent with their lesson plan. The teachers provided a can demo at the beginning of the lesson. An empty can that had little water was boiled on a hot plate until steam filled the can. When the steam came out of the hole in the top, the can was quickly immersed in a container of ice water vertically. Then, the can was crushed making a ‘bang’ sound. Showing this demonstration, a teacher asked students to take notes, their observations about what happened and their explanations for why the can was crushed. Repeating the demo in various conditions, the concept of condensation of water was explained, but not any aspects of NOS.

In the middle/elementary level, as another example, one group taught the phases of the moon. In this lesson, students were provided different phases of the moon and encouraged to develop a model to explain the phases of the moon. At the beginning of the lesson, a teacher mentioned using observations and inferences in developing a model of the earth system. But, that was all.
No further attempt to teach the difference between observations and inferences was identified during the rest of the lesson. Only the correct model of the earth system was discussed and addressed.

The careful analyses of Level 1 lessons indicated that the ICAN teachers’ implicit teaching was not ascribed to the confusion between science processes and aspects of NOS as suggested by Abd-El-Khalick et al. (1998). Rather, on thinking about how to teach NOS, the ICAN teachers intuitively treated NOS as doing things. Their pedagogical knowledge of teaching NOS was related to doing NOS, as is evident in the following quotation from an informal conversation with one ICAN teacher after the first microteaching session:

T (teacher): When we did the first presentation…we did a classifying, we made it so vague. We used empirically-based because you’re observing an object and using that data to help you make your decision. But, I think it was wrong. That’s what we did.

R (researcher): What was your group’s intent?

T: Group’s intent was to use empirically based data which was observations of living and non-living things and how to break them up into categories using their observable features. So if you had an animal with fur and without fur, two different groups, it’s empirical data because using that observable characteristic to make that decision.

R: Did your group explicitly mention that?

T: I don’t think we did. That was whole issue. Nobody understood. Even though we knew what explicit means, we didn’t understand how to make it explicit.

R: Do you know why your group didn’t do that?

T: I think I assumed everyone knew that. I assumed they (the audience of teachers) would pick it up. It doesn’t make sense because when we are doing with students, we know that they wouldn’t know that. I don’t know…it was first time do stuff like that.

(G12M1)

In this lesson, the student participated in inquiry processes, such as making observations and developing a classification theme. As seen above, however, the teacher’s intent was not the scientific processes, but the empirical basis aspect of NOS. Therefore, it is more reasonable to say that the ICAN teachers did not know “how to make it explicit,” assuming that “students
would pick it up” by doing NOS than they believed that students could learn about NOS by going through scientific processes.

**Level 2: Explicit but, NOS as Separate from a Lesson**

A total of 12 lessons at Level 2 were found. Unlike Level 1 lessons that did not show any attempts to teach NOS, the ICAN teachers in Level 2 took time for addressing NOS. The way of integrating NOS in their lessons was to assign a NOS discussion after students’ activities were done. However, this discussion looked separated from the activities that students had been engaged in. Through the activities students were taught science content. After teaching target science content, teachers didactically wrapped up the NOS discussion without a reflective conversation on students’ activities. The activities that students had done appeared to be only for teaching science content. All the Level 2 lessons were identified as concentrating on teaching science content and making a simple didactic explanation of certain aspects of NOS.

For example, one secondary group provided students with three demonstrations regarding heat and temperature. At the beginning of the class, students were asked to define what heat and temperature were. A teacher wrote down students’ definitions on the board. Then, he poured coke in a plastic cup and added some ice cubes to the coke, asking that “now, looking back at your definition of heat, what is happening in this container? Is one object becoming colder or is one object becoming hotter? How is your definition of heat used to describe what’s happening in this little system here?” Students explained what was going to happen based on their own definitions. The teacher then revised some definitions that were inappropriate to explain the demonstration. Two more similar demonstrations were provided and students’ definitions were continuously revised. He came to the final definition of temperature that “temperature is defined as the average amount of kinetic energy in an object.”

After that, the other teacher initiated a discussion on NOS. But, it turned out a short comment rather than a discussion:

“you (students) could make an observation from ice getting smaller and a cup here absorbs food coloring and from those observations you were able to make an inference from your prior knowledge and you knew that molecules move faster and as a group, like scientists do, you were discussing things you knew and things that you were learning as you came up with those definitions…”

(G14M2)
These teachers did not give students the opportunities to reflect on NOS. As shown in the final comment above, students inferred what happened in the cup filled with coke based on their definitions of heat and temperature. The teacher could ask students what they inferred and why they had different inferences and could stress that the concepts of heat and temperature are inferential entities. Rather, they appeared to focus on teaching the concepts of heat and temperature. Actually, in this lesson students were asked about their observations (see italics below) but a teacher made an inference for their observation based on his prior knowledge of the kinetic molecular theory.

T (teacher): We have four or five definitions of temperature. I want to show you different demonstration. Here I have two beakers similar amounts of water. Both hot plates are on…(placing two thermometers in the beakers). I will make a drop of food coloring each of this. I want you to make observations (dropping food coloring).

S 1(student1): Can you tell me temperature?

T: 30 versus 18 degrees

T: What is your first observation?

Ss (Students): Food coloring disperses faster in this (hotter) beaker than in this beaker.

T: So because the temperature of this beaker is higher in this beaker therefore food coloring disperses faster. Now, by knowing that, how could you modify, if you need to, your definition of what temperature is?

S2: Measurement of how fast movement is.

T: Temperature is defined as the average amount of kinetic energy in an object.

(G14M2)

This teacher overly occupied delivering the ‘correct’ concept of heat and temperature rather than pointing out the observation versus inference aspect of NOS that this group targeted in the lesson plan. This group’s interest of teaching the concept of heat and temperature was evidence when looking at their teaching objectives for this lesson.
Instructional Objectives:
1) Students will be able to explain that ‘HEAT’ is an energy transfer between two objects at different temperature.
2) Students will be able to explain that ‘TEMPERATURE’ is the average kinetic energy of the molecules in a substance.

Level 3: Explicit and Reflective Way of Making a Connection with Students’ Doing NOS

Seventeen lessons out of 39 were graded as Level 3. General features of lessons at this Level are to have students exposed to reflective discussions on NOS and to assess students’ understanding of NOS. In teaching certain aspects of NOS in an explicit and reflective way, two different strategies were identified; an inductive NOS discussion and NOS teaching in the whole activity.

An inductive NOS discussion: Nine lessons at Level 3 comprised a NOS discussion at the end of their lessons as Level 2. Unlike Level 2, however, the ICAN teachers in Level 3 lessons led a reflective conversation with students to help them understand certain aspects of NOS by making a connection between students’ activities in the lessons and NOS. One group targeted the electronic circuit. In this lesson students were given materials and asked to light a bulb. Then, a prediction sheet including 14 circuits was provided and students predicted whether each circuit in the prediction sheet would work or not. Finally, they tested their predictions by making the same circuit in the prediction sheet and observing what happened. A teacher gathered students’ test results and helped students understand the structure of electronic circuits. Then, she also addressed the difference between observation and inference aspect of NOS while reviewing students’ results. This group tried to help students reflect on what they did in this lesson for integrating the observation versus inference aspect of NOS. The part of the NOS discussion is shown below.
T (teacher): What do you infer by seeing light bulb light? What’s your inference?
Ss (students): There is electricity.
T: Can you actually see the electricity? Are you observing electricity?
Ss: No.
T: You are inferring electricity is there. What’s another way to know there is electricity?
Ss: The battery gets warm.
T: So for example, in number 9 (circuit in the prediction sheet), the light bulb would not light. Would the battery get warm?
Ss: No.
T: So feeling battery gets warm is observation or inference?
Ss: Observation.
T: So, what would you infer from that?
Ss: So there is current.

One secondary group made a reflective conversation for addressing the observation versus inference aspect of NOS in the context of teaching the fossil evidence for evolution. As an activity, students analyzed the given fossil data and made their explanations, a teacher made a NOS discussion after the activity was done. The questions that she used to help students understand the observation versus inference aspect of NOS included “What did Rudy make? Did he make an observation or did he make an inference?” “How did you infer that?” “Do you think scientists make inferences as they attempt to drive an answer to question about natural phenomena?” “Do you think scientists do the same thing that you guys have done today?” “Can you give me an example?” “Did we see all groups made the same inferences about present day fossils and the past?” “Does anyone come up with any different observations?”

**NOS teaching in the whole activity:** In the other 8 lessons, the ICAN teachers specified target aspects of NOS in the introduction of their lesson and attempts to address the target aspects were identified not only in the discussion at the end of the lesson, but also while students participated in an activity and their group presentation. For example, one group planned an introductory lesson for teaching adaptations for 5th and 6th graders. At the beginning of the lesson, this group prescribed the target aspect of NOS. A teacher said that “the thing that we are gonna focus on
today is to take a look at things and recording observations and making some inferences and distinguishing those two.” Then, two photos of the larval and adult stage of the organism were given to students. The teacher asked them to record their observations and inferences about the photos and fill in the observation and inference sheet. After briefly sharing students’ observations, the teacher made a comment on students’ observations and inferences.

“…It really shows me you already know quite a bit about the difference between observations and inferences. I also noticed that sometimes you can get a little bit tricky. Things that you saw led you to inference so quickly that put in the observation column. Let’s go through couple of examples. I heard one person said that the smaller form had three legs or three extensions coming out of the bottom of the body. And it was inferred that they were legs. Notice I did the same thing. Immediately I inferred…it’s so easy to take your prior knowledge and join that the data you collected during observations and automatically infer something…”

After the preliminary observation, teachers wanted students to design this organism’s habitat. When students finished the imaginative habitat, the student group presented their ideas. During the presentations, the ICAN teachers helped students understand the observation versus inference aspect of NOS.

S (student): We inferred it was originated from water environment. The larva was under ground and then lived in three as an adult.
T (teacher): What observations led you to the inference? You said water environment. What observation led you to that inference?
S: We thought this creature looked like mosquito and so it’s from water environment.

After sharing the designed habitats and discussing the observation versus inference aspect of NOS, teachers summarized and stressed that “each observation that you made led you to many inferences based on your prior knowledge.”

Like this activity, in order to illustrate the observation versus inference aspect of NOS four groups asked students to make observations and inferences (explanations for the observations) in
the context of teaching science content regarding evolution, state of matter, pressure and removing oil on the sea while students were doing an activity. They explicitly mentioned the target aspect of NOS at the beginning of the lesson and provided a piece of observation and inference sheet during a class activity. One of these groups also focused the subjective aspect of NOS. Teachers in the group provided students with four possible and scientific explanations for the air pressure activity that students were involved in. Students were encouraged to compare their own explanations with the more scientific ones. The teachers helped students reflect on the fact that students came up with different explanations and scientists also could have inconsistent interpretations (i.e., four different explanations) due to different prior knowledge.

One middle/elementary group specified the creativity aspect of NOS as introduction and then asked students to predict what a future human skull would look like based on the data showing human skulls from one million years ago to the present. For teaching the tentativeness aspect of NOS, one group provided students four statements regarding creation myths and the big bang theory. Students were also given relevant reading text and then were asked whether they agreed or disagreed with the statements before and after reading the text. Considering a reading assignment regarding creation myths and the big bang theory, students’ change in their idea about those two topics was used to address the tentativeness aspect of NOS. Finally, one middle/elementary group attempted to teach form and function. In this lesson, students watched a video regarding the physical structure of a camel. They were asked to observe the forms of the camel and infer their functions.

The common features shown in these lessons are that the ICAN teachers explicitly stipulated target aspects of NOS in the introduction of a lesson and guided students to observe, infer, be creative, be tentative, and be subjective in order to draw out the observation versus inference, creative, tentative, and subjective aspects of NOS, respectively.

Changes in the Frequency of Levels

In the first microteaching session more than half of groups demonstrated a Level 1 lesson in which students were exposed to hands-on activities, but taught science content only, not the target aspects of NOS. Consistent with prior research (Abd-El-Khalick et al., 1998; Duschl & Wright, 1989; Gess-Newsome & Lederman, 1993), the ICAN teachers did not much consider NOS when planning for microteaching lessons.
Lesson plans heavily focused on teaching science content through hands-on activities. A total of 3 groups (2 from middle/elementary and 1 from secondary level) presented Level 2 lessons. Only in the secondary level did 2 groups implement more successful lessons for teaching NOS.

In the second microteaching session, the number of Level 1 lesson decreased from 8 to 2. After two microteaching sessions, it seems that three more groups moved from Level 1 to Level 2. In the high school groups, there was no change in the number of Level 3 lesson, but 4 middle/elementary groups presented desirable lessons graded as Level 3.

At the end of the ICAN program the third microteaching was performed. All 12 ICAN teacher groups tried at least to illustrate certain aspects of NOS. No Level 1 lessons were found in this microteaching session. It was desirable that the number of Level 2 decreased from six to three and Level 3 increased. However, it was still unfortunate that there were those three groups that presented lessons graded Level 2. Three more Level 3 lessons were presented and therefore, 9 out of 12 groups demonstrated more explicit and reflective approaches. Indeed, in all lessons of Level 3, assessment pieces were assigned for checking students’ understandings of target aspects of NOS. The ICAN teachers provided students with written questions, had them take a quiz, or gave homework including assessment questions.

From this result, it is safe to say that the ICAN teachers improved their pedagogical knowledge related to teaching NOS from an implicit to an explicit and reflective approach. However, implementing explicit and reflective instruction for NOS is not simple. More teachers’ work on effective approaches to explicit and reflective instruction is required.
Factors that impede or facilitate explicit and reflective NOS instruction

Confusion between doing and knowing something

Substantial evidence has been accumulated for the inefficiency of an implicit approach to NOS instruction (Khishe & Abd-El-Khalick, 2002; Moss, Abrams, & Robb, 2001; Sandoval & Morrison, 2003). Therefore, it is likely that doing NOS does not consequently bring about knowing NOS. Indeed, assessing doing NOS is not actually measuring knowing NOS. The quality of students’ experimentation does not necessarily refer to their knowledge of how to do an experiment since it requires more, such as science content knowledge and experimental skills. More importantly, it does not represent their knowledge of the nature of experimentation (Hodson, 1988).

Recognition of the difference between doing and knowing things appears to affect the ICAN teachers’ NOS instruction. As described in Level 1 lessons, the ICAN teachers’ initial belief about teaching NOS was associated with having students a situation of doing NOS. Situations in which students brought up different interpretations, changed their own explanations, created a model, and utilized empirical data were viewed as being subjective, tentative, creative, and empirically-based, respectively. More than half of the ICAN teachers, in the first microteaching, assumed that students would pick up target aspects of NOS only by being exposed to situations of doing NOS without having students discern their doing NOS. They seem to misunderstand that doing something is directly knowing it.

This confusion between doing and knowing was also detected when the ICAN teachers designed the assessment for students’ understanding of NOS. One middle/elementary group was planning to teach the creativity aspect of NOS in the context of teaching the evolution of human skulls. They decided to provide students with data about human skulls of earlier forms and modern human beings and to have students construct a model of a future human skull based on the given data. The point that scientists use their creativity and imaginations in doing science was planned to discuss at the end of the lesson. Here is some part of their conversation for how to assess students’ understanding of the creative aspect of NOS.
T1 (teacher1): This is what I wrote, students are using almost all data to create a futuristic skull of homo sapiens…

T3: And then are you gonna give (students) a rubric one, two, three or…

T2: So, students use all (given data), students use some, and students use none?

…

R (researcher): Are you assessing how to use data?

T1,2,3: No,

T2: We are assessing creativity but…(laughing)

T1: We are assessing whether they are able to be creative within the guideline that they give…

(G3M3)

This group was trying to assess students’ creativity involved in building a human skull model based on the degree of use of the given data. When they were asked if they attempted to assess students’ abilities to use data, they immediately denied it and revealed their intentions for what they were doing. Finally, they realized that they attempted to measure students’ creativity rather than their understanding of the creative aspect of NOS. In the lesson plan for the following microteaching, they planned to ask the questions below.

Did your group use their imagination/creativity in creating your models?

Do you feel that scientists use creativity in creating models?

(G3M3)

Knowledge of how to make it explicit and reflective

The ICAN teachers’ perception on *doing NOS* supports the idea that they saw aspects of NOS in students’ doing activities. However, the awareness of their implicit teaching coupled with *doing NOS* does not necessarily lead to explicit and reflective NOS instruction. In the second microteaching session two ICAN teacher groups still remained at Level 1 and six at Level 2. Even in the third microteaching session, three groups adopted a didactic style. When compared with Level 3 lessons, Level 1 and 2 group teachers needed knowledge of how to make it explicit and reflective.
Two factors seem to be involved in explicit and reflective NOS instruction. First, teachers might need some conceptual understandings of target aspects of NOS. For example, knowing just “scientists can have different interpretations” may not be enough to lead to a reflective discussion for it. In Level 2 lessons, the ICAN teachers attempted to address aspects of NOS asking a common question like “What kind of aspects of nature of science can you see?” (G11M1) “Based on what we’ve done today, what aspects of nature of science and scientific inquiry have we seen today?” (G12M1). Then, they didactically delivered target aspects of NOS like “the thing that we should remember is that not always everybody thinks it in exact same ways” (G4M1). It was not discussed why scientists do not always do things in the same way and how it affects doing science or doing experiments. In this case, adequate knowledge of NOS could bring up reflective questions like ‘why did you have different interpretations of the given data?’, ‘what made you think so?’, and ‘can we easily decide which one is right or wrong? Why or why not?’ Unless teachers know that different interpretations result from different background knowledge including theories, principles, and laws, their NOS discussion will not be elaborated.

Second, interestingly, some ICAN teacher groups appeared to have adequate knowledge of NOS as we analyzed their didactic explanation of NOS, but they failed to facilitate a reflective NOS discussion. Teachers also need knowledge of how to make a connection between doing NOS and aspects of NOS through student-centered discussions, which also requires general pedagogical knowledge of how to guide a reflective discussion.

**Awareness of NOS in science content**

The majority of Level 3 lessons imply that the ICAN teachers were able to see aspects of NOS in doing NOS and to effectively illustrate target aspects of NOS by having students reflect on their doing NOS. With respect to science content, however, the ICAN teachers were not very successful in finding connections between NOS and target science content. They did not very pay attention to the inferential and tentative nature of target science content. Nor did they focus a role for subjectivity in the construction of scientific knowledge. For example, the ICAN teachers were successful in helping students understand what observations and inferences were and the fact that scientists also make inferences based on their prior knowledge. However, the fact that targeted science content was inferential was not addressed. In other words, even thought the distinction between observation and inference was taught in the context of teaching science...
content, such as evolution, magnetism, classification, and electricity, the ICAN teachers did not typically point out that these scientific concepts were not observable, but inferential. Some ICAN teachers did not appear to perceive aspects of NOS embedded in target science content that they focused on in their lessons.

In order to see a connection with science content and address a certain aspect of NOS, teachers may need certain science content knowledge including evidence for the science content and its history of development (Akerson & Abd-El-Khalick, 2003; Schwartz & Lederman, 2002). Based on our observations of their lesson presentations and discussion, we do not doubt that some of the ICAN teachers had an in-depth understanding of scientific knowledge in their field of science. However, what we saw during their lessons was their understandings of the final product of scientific knowledge, not its history of development or substantial grounds for that knowledge. Therefore, we assume that the lack of teachers’ connections between NOS and science content may be, in part, attributed to their lack of certain subject matter knowledge.

The difficulty finding NOS elements in science content was detected in an informal conversation with one high school group who was planning to teach about endocytosis for the first microteaching lesson. They decided to engage students in making a physical model that demonstrates endocytosis. However, they were struggling to insert aspects of NOS into the context of teaching the science content. Even though they knew what endocytosis meant, they did not know how scientists found the process of endocytosis and if they were able to see the process through a microscope. Therefore, they could not grasp the role of scientists’ imagination and creativity in the model of endocytosis and the inferential and tentative nature of the model.

In addition to having sufficient content knowledge, teachers should be able to see aspects of NOS embedded in science content. If teachers could not find elements of NOS through science content, they could not address them. For example, one high school group intended to teach the process of absorption, reflection and transmission of light. At the beginning of the lesson, what would happen when the sun heated the earth was discussed and the three of the vocabulary words were introduced. Students were asked to investigate what happened when the light from a light bulb encountered a piece of black paper, aluminum foil and transparency. After the investigation, a teacher gathered students’ data and summarized them.
T (teacher): Could you tell what happens when sun goes on the black paper? What happens mostly?
Ss (students): Absorption
T: How did you know?
Ss: We can feel the paper was warm enough.
T: Any other they happen with the black paper, some of energy was…
Ss: Reflected…Some of energy was reflected back.
T: Was there any transmission through the black paper?
Ss: No transmission
T: Is there any quality or property in the paper that made it possible for sun to absorb by it?
Ss: Color
T: Color, so you say that all black or dark colors absorb.
S1 (student1): How do we know?
T: You (students) said you felt warm.
S1: How do you know that’s because of color?
T: How is this related to real life? Maybe football coach, what color do you wish to wear to teach soccer team outside when it’s very hot day like 90 degrees?
S1: But, it’s based on your prior knowledge.
(After some argument)
T: Anyway, let’s go through this first.

One student (S1, see italics above) from the audience pointed out the inference that black color absorbed the light. Then, the teacher occupied herself with convincing the student that black color absorbed sunlight, but it seemed that she could not recognize the relationship between black paper getting warmer (observation) and black color absorbs sunlight (inference). Rather, she treated it as an absolute fact as giving the student a football coach example. We assume that she neither understand how scientists know that black color absorbs sunlight nor discern the inferential nature of that knowledge.

On the other hand, one middle/elementary group successfully illustrated the inferential nature of the stage of matter. In the lesson, students were asked to define the characteristics of gas, liquid, and solid. Then, they observed a jelly-like mystery object (ooblick) and determined whether it was liquid or solid. In a debriefing, the inferential nature of stages of matter and how to solve the disagreement on the stage of the ooblick was discussed. **We assume that if the**
teachers thought of stages of matter as an ontologically fixed concept, they might struggle to address the inferential aspect of NOS embedded in the content of stages of matter.

Therefore, it seems that teachers need to have sufficient science content knowledge and ability to discern NOS in the conceptual structure of the science content.

**Discussion and Implications**

The results of this study indicate that there are two critical changes that need to occur in order to implement explicit and reflective NOS instruction. First, teachers need to realize that explicit is better than implicit instruction. Even though several explicit activities and explanation for the difference between explicit and implicit NOS instruction were given before, in the first microteaching session, 8 of 13 groups adopted implicit instruction. The teachers initially believed that students could learn about NOS by only doing NOS. They confused doing something with knowing it (e.g., Abd-El-Khalick et al., 1998). Extensive experience is needed for them to realize that they are adopting an implicit approach which is not effective in teaching NOS and to understand that doing something is not necessarily knowing it.

Second, teachers need to be aware that a student-centered approach to explicit and reflective is better than a didactic approach. The result that only 2 among 14 lessons in the second microteaching session were classified as Level 1 seems to indicate that most ICAN teachers realized their implicit teaching of NOS after the first microteaching session. However, discerning this implicit approach was not sufficient for some ICAN teachers to implement explicit and reflective NOS instruction. With the exception of some middle/elementary groups that moved to Level 3, many of the groups at Level 1 in the first microteaching session moved to Level 2 in the next session. This means they intended to explicitly teach NOS, but failed to address target aspects of NOS in an explicit and reflective manner advocated by Project ICAN. A short and didactic discussion for NOS was assigned at the end of a lesson rather than a reflective and interactive conversation.

Knowing NOS-pedagogical knowledge (e.g., the difference between an implicit and an explicit approach) does not seem to be enough to entail the changes from didactic to reflective NOS instruction. Teachers need pedagogical content knowledge (PCK) for NOS instruction that
includes sufficient knowledge of NOS, certain science content knowledge (e.g., its evidence and history of its development), general pedagogical knowledge of generating a student-centered discussion, and NOS-specific pedagogical knowledge of making connections between what student do and what scientists do and between NOS and the conceptual structure of science content. During the third microteaching session, 75 percent (9 of 12) and 25 percent (3 of 12) of the ICAN teacher groups presented Level 3 and Level 2 lessons, respectively. No Level 1 lessons were identified. The change from six lessons (43%) in Level 3 in the second microteaching session to nine lesions (75%) indicates that around 30 percent of the ICAN teachers improved their PCK for NOS instruction.

From the data analyses, this movement from Level 1 to Level 2 to Level 3 seems to be a developmental continuum of PCK with respect to NOS instruction.

Let us describe an example regarding understanding about inquiry for an extensive understanding of this PCK developmental continuum. Suppose that a teacher is planning to teach 7th graders one aspect of understandings about inquiry that ‘scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories (NRC, 2000, P.20).’ She has an adequate view of this aspect of understandings about inquiry. We expect that the teacher’s initial attempt to address this aspect might have students observe particular phenomena and develop an explanation for them. She would be concerned with whether students’ explanations are derived from their evidence. Students would be asked to provide pieces of evidence for their explanations. From this lesson, she might believe that students could learn about the aspect of understandings about inquiry because students would do it. As the first step of the PCK development for explicit and reflective instruction for scientific inquiry, this teacher needs to recognize that she engages in an implicit teaching that is not effective in helping students understand the aspect of understandings about inquiry. Consequently, she needs to know that an explicit approach is more effective than implicit instruction.

However, the recognition of an explicit approach might not guarantee successful instruction for illustrating the aspect of understanding about inquiry. Unless the teacher could know how to help students reflect on the target aspect of understanding about inquiry, the teacher might advocate a didactic style in addressing the target aspect.
As the second step of the PCK development, she should realize that a student-centered approach to explicit and reflective is better than a didactic style. In engaging in an explicit and reflective approach, she might feel easier to link what students would do in a lesson to the target aspect of understanding about inquiry with reflective questions. Those questions would include ‘why is your explanation weaker or stronger than other explanations?’, ‘what if an explanation is not consistent with evidence?’, and ‘what makes scientists’ explanations scientific?’, etc.

The teacher’s initial attempt to assess her students’ understanding of this aspect of scientific inquiry might be on how much students’ explanation is logically consistent with evidence. This assessment is actually targeting students’ reasoning skills and relevant background knowledge, which is more related to skills.

Indeed, it might be a challenge task for her to address how a certain scientific explanation (e.g., magnetism, evolution, and kinetic molecular theory) is logically and consistently supported by its evidence using scientific principles or pertinent theories unless she knows the theoretical framework of that explanation.

The PCK model for NOS suggested by Schwartz and Lederman (2002) defines a teacher’s PCK for NOS as the integration of NOS knowledge, subject matter knowledge, and pedagogical knowledge. The findings from the present study elaborate this PCK model that Schwartz and Lederman suggested. In terms of subject matter knowledge, an adequate understanding of a scientific concept as the final product is necessary, but insufficient. Relevant knowledge of the scientific concept, such as the history of its development and its empirical grounds, is necessary. In addition, NOS-specific pedagogical knowledge includes knowledge of the difference between an implicit and an explicit approach and between a didactic and an explicit and reflective approach.

However, it should be emphasized that the PCK for teaching NOS can be revealed as those three domains of knowledge are integrated. Extensive experience should be provided to teachers to discern this integration among those domains of knowledge. For instance, in-depth subject matter knowledge can be useful and meaningful as teachers are able to find aspects of NOS and to integrate them into classroom lessons.

The results from the present study indicate that the ICAN teachers improved their NOS instruction through three microteaching practices. They became proficient at connecting what students did in their lessons to what scientists do, illustrating a certain aspect of NOS. Not only
did they find opportunities to integrate NOS from student activities in their lessons, but they also intentionally had students exposed to certain situations of doing NOS to increase opportunities to engage in explicit and reflective NOS instruction. In connecting NOS to doing NOS, it is not surprising that the difference between observations and inferences was the most frequent aspect of NOS that the ICAN teachers addressed. Ten out of 17 Level 3 lessons included this aspect. The ICAN teachers may have felt comfortable to incorporate this aspect of NOS within their lessons because making observations and inferences were common features of any investigations. In the same line, teachers may have faced difficulties making a situation for the socially and culturally-embedded and the theory versus law aspect of NOS that were rarely illustrated in microteaching lessons. It might challenge them to design a situation of doing NOS associated with these aspects of NOS.

Relatively, the ICAN teachers were not very successful in connecting between NOS and science content even though we provided most activities in the context of teaching science content and pointed out the inferential, subjective, and tentative nature of the science content knowledge. One example is the activity of mystery bones of a dinosaur. As comparing the paleontologist’s imagination to the ICAN teachers’ imaginative structures of mystery bones, why and how aspects of NOS are involved in the knowledge of dinosaur structures built upon evidence including fossils, bones, and footprints. It seems that some ICAN teachers could not see the connection between NOS and the final product of scientific knowledge through this kind of activity or they could not transfer what they saw in this science content into other science content (Abd-El-Khalick, 2001; Akerson & Abd-El-Khalick, 2003). On the other hand, this result could be interpreted that the ICAN teachers felt more comfortable or easier to connect NOS to what students do than to what they learn (i.e., science content). The ICAN teachers did not appear to struggle to use hands-on and investigation-based activities for teaching science content. In fact, all the activities that the ICAN teacher groups used were common curricular materials. Without challenging their subject matter knowledge, we assume that the ICAN teachers could first find and incorporate NOS with doing NOS in those hands-on and investigation-based activities. Nevertheless, more research on helping teachers integrate NOS with the conceptual and developmental structure of science content is necessary.

The next question is concerning what affected the ICAN teachers’ development of their PCK for NOS instruction. As pointed out, changes from implicit to explicit and reflective NOS
instruction requires not only NOS knowledge but also pedagogical knowledge related to teaching NOS and subject matter knowledge. Finding out all possible explanations for this improvement is beyond the scope of this study. But, it seems to be evident that three microteaching practices provided the ICAN teachers with a great deal of opportunities to reflect on their understanding of NOS, and pedagogical knowledge, and, in part, subject matter knowledge. One teacher’s comment on her peers’ group presentation in the first microteaching is an example:

I think the last class, when we had the group who did creatures making with celery and carrot…That helped a lot and they were very explicit and then Norm and Judy explained a lot more. Once that’s done, I understood how to be explicit.

(G3M1)

Teachers’ awareness of their implicit teaching challenged their understanding of NOS as well. After the first microteaching session, informal notes showed two common questions of what implicit and/or explicit means and of what certain aspect (e.g., tentativeness, empirically-based, etc) of NOS means. One teacher said that “one I get very confused on is empirically-based… how is that different from regular observations?” The process of resolving the confusion between doing and knowing seems to require teachers to clarify their understanding of NOS.

It should be also mentioned the importance of the assessment practice. The ICAN teachers’ task on how and what to assess in terms of NOS can reveal the confusion between doing something and knowing it as well as their knowledge of NOS. Therefore, requesting teachers to make a plan for assessment of students’ understanding of NOS plays a role in stressing that NOS should be a cognitive outcome (Bell et al., 2000), and in diagnosing their NOS knowledge and NOS-specific pedagogical knowledge.

The ICAN teachers planned and presented their microteaching lessons three times and had the opportunity to observe 19 to 20 peer lessons and discuss those lessons. It seems that the microteaching practices made the ICAN teachers familiar with teaching NOS and helped them reflect and develop their PCK related to NOS.

However, much work needs to be done. Teaching NOS effectively is not simple, given what teachers currently do. More research is needed on helping teachers elaborate their perception of NOS within the context of science content and improve their NOS instruction. Indeed, it is
important to realize that there is little data to discriminate whether one type of explicit is better than another type of explicit.
References


