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Inquiry-Based Professional Development: What does it take to support teachers in learning about inquiry and nature of science?

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This study examined the geologic and evolutionary subject matter and views of inquiry and nature of science (NOS) of a group of 5th–9th grade teachers, and a comparison group, before and after participating in an inquiry-based professional development (PD) experience. Project teachers participated in an intensive, week-long, resident institute where they learned about geology, evolutionary concepts, NOS, and inquiry while engaging in an authentic scientific investigation. They were also given support in how to teach these topics using an inquiry-based approach. Analyses of data indicate that project teachers showed greater gains in subject matter than comparison teachers and the relative change was significantly different statistically. Furthermore, most project teachers demonstrated a shift from less informed to more informed views of inquiry and NOS and the relative change between participant and comparison teachers was significantly different statistically. These gains are promising because they suggest that short-term and intensive PD can support teachers in enhancing their knowledge and views. Moreover, analysis of post-programme questionnaires and interviews indicated that supporting teachers in reflecting on the relationship between their former classroom teaching practice, and new knowledge acquired during PD, may be an important link in enhancing teacher knowledge and supporting change in practice. This suggests that enhanced knowledge and views may not be the only factor contributing to changing one's practice. The study points to the importance of reflection in promoting teacher change. Results from this study add insights to supporting teachers in enacting inquiry-based instruction and teaching about NOS in their classrooms.

Keywords: *In-service; Inquiry-based teaching; Nature of science*

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Inquiry-based instruction and explicit teaching of nature of science (NOS) are important components of reform-based science teaching in the USA (National Research Council [NRC], 1996, 2000, 2012). Combining inquiry instruction with explicit attention to NOS is one way to promote scientific literacy (Hodson, 1992) and potentially contribute to improving both student achievement and engagement in science (American Association for the Advancement of Science, 1989, 1993; NRC, 1996). Unfortunately, few classroom teachers have had the opportunity to participate in scientific inquiry and even some of the most highly qualified teachers have been shown to have limited knowledge of inquiry and NOS (Capps & Crawford, in press). This lack of experience and knowledge puts serious limitations on many teachers' ability to teach through inquiry and about NOS. It is commonly thought that teacher knowledge affects classroom practice (Cochran-Smith & Lytle, 1999). Thus, the interaction between teacher knowledge and practice related to inquiry and NOS is an important locus of study in science education research. Teaching through inquiry and about NOS are complex and sophisticated ways of teaching that demand significant professional development (PD) (Crawford, 2000, 2007; Lederman, 1999). Furthermore, it may be the case that active reflection plays a role in enhancing knowledge of these concepts (Schwartz, Lederman, & Crawford, 2004). Without PD support, including giving teachers opportunity for reflection, it is unlikely that teachers will be successful in enacting inquiry-based instruction or explicit NOS instruction.

To address the inconsistency between reform documents that advocate inquiry and NOS instruction in science classrooms and what is actually occurring in most classrooms, we developed the Fossil Finders. Fossil Finders is a multiple-year research project that focuses on supporting fifth to ninth grade teachers and their students in learning about inquiry, NOS, earth science, and evolutionary concepts through an authentic research investigation. As part of the Fossil Finders project we created a two-year PD programme aimed at enhancing teachers' understanding of inquiry, NOS, and science concepts; supporting them in reflecting on their knowledge and teaching practice; and preparing them to use inquiry-based instruction and explicit instruction related to inquiry and NOS in their classrooms. Effectively, our aim was to create a learning experience, 'powerful enough to transform teachers' classroom practice' (Putnam & Borko, 2000, p. 5). Although Fossil Finders is a multiple-year research project, in this study we examined the influence of an intensive, week-long summer institute on teacher knowledge and views. We asked the following questions:

(1) What was the influence of an authentic inquiry-based PD experience on teachers' knowledge of subject matter and views of inquiry and NOS?
(2) How, if at all, did teachers reflect on their former teaching and discuss their intentions to teach science as inquiry or about NOS?

Theoretical Framework

Teacher PD

Teacher PD is regarded as a cornerstone for the implementation of reform-based teaching (Committee on Science and Mathematics Teacher Preparation, 2001).

Although there is no single formula for effective teacher PD, there is consensus on a variety of features of PD that support teachers in learning and enacting reform-based instruction in their classrooms (e.g. Bell & Gilbert, 1996; Darling-Hammond & McLaughlin, 1995; Desimone, 2009; Garet, Porter, Desimone, Birman, & Yoon, 2001; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Capps, Crawford, and Constas (2012) synthesised the literature on general teacher PD and specific inquiry-focused PD to identify a set of features of effective inquiry PD. Included in these features were: adequate time for teacher learning; extended support that goes beyond the initial PD workshop; opportunities to participate in authentic inquiry experiences during the workshop; curriculum and materials that are aligned with local, state, and national standards; opportunities to develop inquiry-based lessons during the workshop; opportunities to participate in modelled inquiry experiences during the workshop; time and support to reflect on one's experience; support transferring what was learned into the classrooms; and a focus on teacher content knowledge. Although each of these features is important to teacher growth, Capps et al. (2012) identified the need for studies that explore which of these features are most critical. Two features of effective PD that were least frequently addressed in the programmes reviewed were authentic inquiry experiences for teachers and a focus on teacher content knowledge. A focus on teacher knowledge is one of the most imperative features supporting teacher growth (Birman, Desimone, Porter, & Garet, 2000; Kennedy, 1998). It seems intuitive that teachers who have more robust knowledge and have participated in their own inquiries will be better positioned to make changes in their practice, whereas teachers who lack sufficient subject matter knowledge or have inadequate understandings of inquiry and NOS will struggle to teach their subject and have difficulties enacting teaching strategies like inquiry-based instruction. Thus, supporting teachers in enhancing their knowledge is crucial.

Inquiry and NOS

Scientific inquiry has been referred to as, 'the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work' (NRC, 1996, p. 23). Scientific inquiry can also be thought of as science practised by scientists (Chinn & Malhotra, 2002). Inquiry-based instruction resembles scientific inquiry by engaging students in instruction that parallels the work of scientists. In the USA, classroom inquiry has been operationalised through the five essential features of inquiry which include the learner: asking and answering scientifically oriented questions, giving priority to evidence in responding to questions, coming up with explanations using evidence, connecting explanations to scientific knowledge, and communicating and justifying explanations (NRC, 2000). This type of instruction has been relatively uncommon in US classrooms (Anderson, 2002; Capps & Crawford, in press; Stake & Easley, 1978). This might be due to the fact that many current teachers learned science through more traditional approaches or because teachers do not understand what inquiry is (Anderson, 2007). Recently, inquiry-based instruction has been reframed as a set of scientific practices derived from what scientists do in their work (NRC, 2012). At the heart of these practices is the learner, who through this process, grapples with data to make sense of some event or phenomenon. Inquiry, or engaging students in scientific practices, is not the only approach to teach science (Anderson, 2002), but it is important because it is grounded in current education theory and is congruent with how we think people learn. For example as learners investigate the natural world they construct meaning through their interactions with objects in the environment as well as with their peers and teacher (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Engaging students in the practices of science is also important because it provides a productive context to learn about NOS (Carey & Smith, 1993; Schwartz et al., 2004).

The nature of scientific knowledge refers to an understanding of science as a way of knowing (Abd-El-Khalick, Bell, & Lederman, 1998). There are a variety of different viewpoints on the actual NOS. We take the position of Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) in the description of a set of seven aspects of NOS based in historical, philosophical, and sociological studies that are important and feasible to teach students. These aspects include the following: scientific knowledge (a) is tentative, (b) is partially subjective (i.e. theory laden), (c) relies on an empirical basis, (d) is creative, (e) is socially and culturally embedded, (f) is based upon observations and inferences, and (g) theories and laws are different forms of scientific knowledge. It has been suggested that implicit teaching of NOS is not adequate and that these components should be explicitly taught in the classroom (Schwartz et al., 2004). Past studies have shown that many teachers and preservice teachers do not hold adequate views of NOS (Abd-El-Khalick & BouJaoude, 1997; Akerson & Donnelly, 2008; Carey & Stauss, 1970; Lederman, 1992). It seems reasonable to assume that inadequate views of NOS held by teachers may prevent them from teaching about NOS.

Teacher Knowledge and Reflection

There are a variety of ways to conceptualise teacher knowledge. Two primary forms of teacher knowledge discussed in the literature are content knowledge and practical knowledge. Content knowledge in science includes: knowledge of specific science subject matter (e.g. geology, NOS), knowledge about what scientific inquiry is (both as a process and what scientists do), and knowledge about classroom inquiry (NRC, 2000). Reform-based practices like teaching through inquiry and about inquiry and NOS, are sophisticated ways of teaching that require a critical amount of content knowledge (Magnusson, Krajcik, & Borko, 2002). A teacher's practical knowledge also affects classroom teaching. Practical knowledge is the knowledge one has as a result of their teaching experience (van Driel, Beijaard, & Verloop, 2001; Fenstermacher, 1994). Practical knowledge is believed to be dynamic and open to change (Elbaz, 1981). In considering classroom teaching practice related to inquiry and NOS, it is important to understand how both content knowledge and practical knowledge influence what teachers' know and what they do. As we better understand the interaction between these types of knowledge we will be better able to support teachers in developing sophisticated pedagogical skills including learning to teach science as inquiry and teaching about NOS.

One way to understand the complicated relationship between teacher knowledge and practice is through reflective comments made by teachers. Reflection has been framed in a myriad ways in teacher education (Grimmett & Erickson, 1988; Richardson, 1990). We take the position that reflection is more than merely keeping a journal or superficially thinking about a lesson or experience. It is the ability to critically examine one's views and practice in light of new experiences and knowledge. The act of using knowledge and experience to reflect on one's teaching can be a valuable tool for teacher learning and teacher change (Dewey, 1933; Loughran, 2002; Schön, 1983). This is especially true as teachers enhance their knowledge through professional learning experiences related to reform-based teaching (Keys & Bryan, 2001). Reflection on inquiry experiences may help to situate new knowledge in one's classroom teaching, promoting teacher learning and change in practice (Windschitl, 2003).

Purpose of the Study

A recent study revealed that a group of highly motivated, well-qualified teachers believed they were teaching science as inquiry when, in actuality, they were not (Capps & Crawford, in press). Furthermore, none of the teachers were teaching explicitly about NOS. Interestingly, few teachers in the study held adequate views of inquiry and NOS and there appeared to be a relationship between their views and their practice. This highlighted the important need for well-designed PD that supports teachers in learning about inquiry and NOS in order to promote this type of instruction in their classrooms. It has been argued that it is 'difficult if not impossible to teach in ways in which one has not learned' (Loucks-Horsley et al., 2003, p. 1). Thus, if we expect teachers to use new pedagogical approaches they will need to have learning experiences that familiarise them with these approaches, along with support in comparing how these learning experiences relate to their actual teaching practice. The purpose of this study was to describe changes in teachers' knowledge and views after participating in a relatively short, yet intensive summer PD. The PD engaged teachers in authentic inquiry-based experiences and provided support for them in articulating their views of inquiry and NOS.

Context of Study

This study was conducted within the Fossil Finders. Fossil Finders is a multi-year National Science Foundation (NSF) funded project involving the collaboration between a large research university, a natural history museum, and a total of 30 teachers from across the USA. An innovative, two-year PD programme was designed to support two pilot groups of teachers (10 teachers in the pilot year one pilot and 20 teachers in year two). The PD was combined with the development of innovative curriculum materials, the development of a website and database, and the opportunity for teachers and students to work with paleontologists on an authentic scientific investigation. A central focus of the PD was to engage teachers in the learning of science content by participating in an authentic inquiry investigation. Participant teachers would later conduct a similar investigation with their students. The PD programme targeted three areas: inquiry-based teaching strategies, NOS, and geology and evolutionary concepts. This study focuses on the second pilot group of teachers during their first year of PD.

Participants

We selected 20 teachers from an applicant pool of over 80 teachers from across the USA. Selection criteria included: quantity of college science courses taken, presence or absence of science research experience, teaching experience (years), quantity of science PD, what they hoped to gain, their willingness to participate in all phases of the project, alignment of the project with their curriculum, and evidence of a supportive school administration. We strove to obtain an even distribution of fifth to eighth grade teachers with a range of coursework and experience with science (see Table 1 for teachers' backgrounds). This was appropriate since unlike high school teachers, who are generally content specialists, middle-level science teachers (fifth to eighth grade) range from having very little experience with science to having quite a lot. Thus, the range in experience in our sample is likely representative of middle-level science teachers in the USA. All but two of these teachers (Kari and Olga) taught multiple periods of science each day making them the science specialist for their grade level. This departmentalisation is fairly common at the middle level in the USA. Each of the selected teachers was paid a stipend for participating in the project. Teachers also received curriculum materials, a digital camera, and the use of a laptop computer. All twenty project teachers were invited to participate in the education research study, and all agreed and signed human subjects consent forms. We collected complete data sets for 18 of the 20 participants. From this point on, only data from these 18 teachers will be included in the study. Because random assignment was not an option, we asked participant teachers to select a comparison teacher. In selecting these teachers we asked participants to choose a comparison teacher who taught the same grade level and subject matter, and had similar teaching experiences and educational background, in order to approximate equivalence (Wayne, Yoon, Zhu, Cronen, & Garet, 2008). In most cases, comparison teachers were located in the same school or school district. If this was not possible, teachers were asked to find a comparison teacher from a school with similar characteristics to their own. Comparison teachers received a small stipend for their participation.

Teacher PD: Summer Institute

The summer institute took place in the northeastern USA. The resident institute was held in early August at a university and a natural history museum, and it consisted of approximately 60 hours of instructional time. The primary goal of the

Table 1. List of teachers involved in the programme and their background information

Teacher	Grade level	Education	Teaching exp. (yrs)	College sci. courses	Research exp.	Sci. PD exp.	Gender
Albert	5th	BS-Electrical Eng.[a]	14	15	Yes	2	M
Amanda	5th–8th	BA-Sci. Ed.[a]	5	6	No	5	F
Brit	6th	BA-Elementary Ed.[a]	4	3	No	0	F
Curt	8th	BA-Elementary Ed.[a]	9	10	Yes	1	M
Caelyn	5th	BS-Elementary Ed.	2	7	No	2	F
Darlene	7th	BA-Fine Arts[a]	10	7	Yes	4	F
Flo	6th	BS-Physical Therapy[a]	19	4	No	8	F
Gabby	8th	BA-Anthropology, MA-Museum Stud.	5	16	No	3	F
Gary	7th	BA-Bio. and Chem., MS-Biochem.	13	25	Yes	2	M
Kari	5th	BA-Education[a]	20	2	No	3	F
Kate	7th	BS-Chemistry[a]	3	14	No	1	F
Keene	6th–8th	BS-Biology, MS Entomology	6	18	Yes	3	F
Kendra	7th	BS-Biology[a]	5	16	Yes	0	F
Olga	5th	BS-Education[a]	23	1	No	1	F
Pam	7th	BS-Elementary Ed.	32	7	No	10	F
Paula	6th–8th	BS-Elementary Ed.[a]	22	9	No	3	F
Pris	7th	BA-Bio./Chem. MA-Bio.-Geography	22	32	Yes	4	F
Ron	8th	BS-Science Ed.	2	21	No	1	M
Avg			12.0	11.8		2.9	

Note: Shaded rows represent those teachers that made reflective comments.

[a]Denotes a master's in education

institute was to create an authentic context to enhance teachers' understandings of science content knowledge including evolution, geology, inquiry, and NOS. Furthermore teachers were supported in learning the practices of science (see new K-12 Framework, NRC, 2012) and in enhancing their pedagogical practice, towards a more inquiry-based approach. Teachers engaged in the Fossil Finders curriculum and materials as learners, participated in several paleontology/geology field trips, and collected and analysed data as they took part in the scientific investigation. Further, teachers were supported in critically reflecting on their experiences and their prior teaching.

Throughout the summer institute, instructors modelled how to teach each background lesson using an inquiry approach. The lessons and instructional materials aligned with grade level science content and the guidelines for inquiry and NOS for the teachers involved in the project (see Table 2 for a list of Fossil Finders lessons with descriptions). Special attention was given to explicitly highlighting aspects of

Table 2. List of Fossil Finders lessons with descriptions

Lesson name	Description
Tricky Tracks	This lesson is an adaptation of Proposing Explanations for Fossil Footprints (NAS, 1998) which engages students in learning NOS. Students will learn about making observations and inferences based on evidence. In this lesson, students will be introduced to the work of paleontologists and engage in interpreting the geologic past. The activity encourages students to observe and make inferences about evidence related to a partially complete set of animal tracks. Students will use their observations to interpret what they see. Student may be paired to make predictions, compare results, and discuss their findings
Investigating Fossils	This lesson engages students in an exploration of fossils. As a background component of the Fossil Finders Investigation, students will learn about what fossils are and how they formed. In this lesson, students will be introduced to the work of paleontologists by working in pairs to observe, draw, and make inferences about fossils. Students will use their observations and their prior knowledge of the environment and modern day processes to make inferences about the environments in which fossilised organisms once lived. Student pairs make predictions, compare results, and discuss their findings. Students will also learn about aspects of NOS, including subjectivity, observations and inferences
What do Geologists do?	This lesson engages students in an exploration that parallels what geologists do. In the activity, students will make observations about the accumulation of paper in a recycling bin and use this information to make inferences about the past. Students will see that by obtaining more information, they can begin to get a clearer picture of what may have occurred in the past. In this lesson students will learn about the principles of superposition and relative-age dating
Classroom Population Study	This lesson engages students in an exploration of population data. Students will learn about making observations and inferences based on their own measurements. In this lesson, students will be introduced to statistical concepts, graphing data and analysing and comparing compiled data
Measuring Fossils	This lesson assists students in learning how to identify, count, and measure Devonian fossils from central New York. Students will also learn to process the data that they gather using data recording sheets. This activity parallels the work of data collection in paleontology and will give students a chance to practise collecting data before they collect it for the Fossil Finders Investigation
Fossil Finders Investigation	This five-day paleontological investigation engages students in authentic scientific inquiry. Through this investigation there are many opportunities to discuss evolutionary, geological, and NOS concepts. Students will learn about collecting, compiling, and interpreting data related to a population of fossils. After collecting the data, students will enter their data into an online database and analyse and interpret the data they collected. The online database can also be used to share data with other classes, scientists, and look for trends in the data beyond one's own class

inquiry and NOS in the lessons. Project teachers participated in these activities from the perspective of learners and discussed how they could enact these lessons in their own classrooms. Teachers also visited several field sites with scientists. The purpose of the field trips was to learn basic geological principles and how to identify fossils, and to better understand the overall geological context of scientific research study in the Devonian Period in central New York. Field trips were designed and led by paleontologists with the support of education researchers. While in the field, teachers observed fossil bearing rocks from several Middle Devonian Period sites and were guided by scientists in making inferences about the geological history of each site and how the different sites related to one another. Participants collected rock and fossil samples from each site. These samples would later serve as reference sets and teaching samples in their classrooms. At one site, in Pompey, NY, teachers collected scientific samples for the actual Fossil Finders investigation that would later be conducted in classrooms. Samples were taken from specific stratigraphic layers as part of the research being carried out with the partnering paleontologists. Teachers analysed some of these samples during the summer institute as they themselves participated in the investigation. Teachers collected data from the samples they had gathered from the research site, measured and identified organisms in the rocks, and recorded the degree of fragmentation of the fossils and the rock colour. They then entered the data into an interactive online database connected to the project's website. Scientists supported teachers in using the data as evidence to make inferences about how marine organisms changed in response to environmental changes in the Devonian Sea. The remaining samples collected by teachers were shipped to each teacher's school and would be used when the teacher conducted the investigation with his or her students.

In addition to situating teachers' science learning within the authentic investigation, we engaged teachers in the pedagogy of inquiry and explicitly taught about aspects of NOS. Teachers were introduced to the essential features of inquiry (NRC, 2000) and aspects of NOS reported to be accessible to K-12 students (Lederman et al., 2002). Education researchers and scientists worked together as a PD team in order to make explicit connections between the scientific investigation and pedagogical activities. The PD team assigned readings and asked teachers to write reflections about the readings and post these on an online discussion board. PD staff members facilitated discussions, and provided examples of how to explicitly teach about NOS and use inquiry-based teaching approaches. Teachers were also given time to write about and discuss in a whole group how their current classroom practice related to or differed from what they were learning about inquiry and NOS. Thus, teachers had many opportunities to consider how they might enact this type of instruction in their classrooms. Opportunities for reflection on inquiry and NOS were integrated throughout the six-day summer institute.

Data Collection and Analysis

We employed a mixed methods approach combining quantitative and qualitative data (Creswell, 2009). Data sources included a pre–post instrument, consisting of a subject matter knowledge assessment and open-response views of inquiry and NOS questionnaire. We also conducted pre-and post-interviews with a subset of teachers. We purposively selected 11 teachers to interview, because first, these teachers represented a wide range of pre-programme teaching practices; and second, we had a complete data set for each of these teachers. The aim of the study was to determine the influence of the authentic inquiry-based PD experience on teachers' knowledge of subject matter, views of inquiry, and NOS. We used a quasi-experimental, non-equivalent control group design (Campbell & Stanley, 1963) to compare participant teachers' pre–post subject matter knowledge and views of inquiry and NOS scores with a group of comparison teachers who were not involved in the project. We also reviewed pre–post-views questionnaires and conducted interviews with a subset of teachers immediately before the summer institute and approximately one-month after the institute to look for evidence that the PD influenced teachers to be reflective on their teaching practice.

Influence on Teacher Knowledge and Views

An identical pre–post written instrument was administered online to participant and comparison teachers a week before and a week after the summer institute. The written instrument included two parts: a subject matter knowledge assessment; and an open-response, views of inquiry and NOS questionnaire. The first part of the instrument, the subject matter assessment, was developed by education researchers and scientists involved in the Fossil Finders project to measure teachers' knowledge of geology and evolutionary concepts. It was constructed by compiling a list of concepts that addressed the goals and content of the Fossil Finders project. Using this concept inventory, we identified a number of valid and reliable items from existing instruments that matched these concepts (see Appendix 1 for a list of the instruments). In several cases, where no existing item aligned with our concept inventory, we developed new items or modified existing items in order to align the assessment with project content. The subject matter assessment consisted of 24 items, including 10 multiple-choice questions with one correct answer, nine multiple-choice questions with multiple correct answers, and five open-response items (see Appendix 1 for selected items from the 24-item subject matter knowledge assessment). We developed an answer key to score each of the multiple-choice items and a scoring rubric for the five open-response items. Eighteen participant teachers completed the pre- and post-knowledge assessment, whereas 15 comparison teachers completed the pre-knowledge assessment and 11 completed the post. Analysis of covariance (ANCOVA) was selected to assess treatment effects. Teacher score on the pre-subject knowledge assessment was used as the covariate in the analysis to control for regression towards the mean. We used the following model: change = pre score + treatment. Only those teachers who completed the pre- and post-assessment were included in the model.

Teachers' views of inquiry and NOS were assessed using a validated questionnaire along with interviews of a subset of teachers. We developed the questionnaire, or the second part of the instrument, over a period of two years drawing on elements of inquiry and inquiry-based instruction defined in *Inquiry and the National Science Education Standards* (NRC, 2000) and aspects of NOS reported to be accessible in K-12 classrooms (Lederman et al., 2002). The views questionnaire consisted of 17-items, all of which were open-response (see Appendix 1 for the 17-item questionnaire). We developed our scoring scale based on Lederman et al. (2002); however, we modified the original two-point scale (0 or 1) representing more naive and more informed to a four-point scale (0, 1, 2, 3) representing naive, emerging, informed, or robust understandings of inquiry and NOS. We used teacher responses from our study along with illustrative examples from Lederman et al. (2002) to develop our scale (see Table 3 for an example of how the scale was developed). The four-point scale was finer grained and a more clearly highlighted variance across our population of teachers. Thus, mean scores for each item are reported out of a total of 3.0. Initially, each item was scored independently by two researchers. Throughout the process, the coders consulted with one another to ensure agreement on scores. Interviews were used to validate researchers' interpretations (see Appendix 1 for interview questions). Next, we analysed each teacher's responses vertically, across all of the items on the instrument. This helped us to place difficult responses into context since often times a teacher's answer on one item could inform our scoring of a related item.

Table 3. Example of the four-point scoring scale for a question about the scientific method developed using illustrative examples from Lederman et al. (2002)

'The scientific method' current study			
Uninformed (0)	Emerging (1)	More informed (2)	Robust (3)
Does not know or says, scientific method must be used, or good science must follow the scientific method	Indicates that the scientific method is more flexible than commonly believed (e.g. not all of the steps are always necessary, specific order of steps is not important)	Indicates that there are multiple methods of science (beyond the understanding as in 1). (e.g. not all science is experimental, or some scientific investigations are observational or descriptive)	Indicates that there are multiple methods of scientific investigation (as in 2) both within scientific discipline and across different scientific disciplines AND/OR science depends on the question(s) posed
'The scientific method' Lederman et al. (2002)			
More naive		More informed	
Science deals with using an exact method .... That way we know we have the right answer		When you are in sixth grade you learn that here is the scientific method and the first thing you do this, and the second thing you do that and so on ... That's how we may say we do science, but [it is different from] ... the way that we actually do science	

Note: The four-point scale was finer grained and more clearly highlighted variance across the population of teachers in the current study.

Finally, we conducted a horizontal analysis for each item across our participants to ensure consistency and fine tune the scoring rubric. Inter-rater agreement among the coders approached 95%. When there was a disagreement on the final score of an item, we discussed it until we reached consensus. Eighteen participant teachers completed the pre-views questionnaire and 17 completed the post, whereas 15 comparison teachers completed the pre-views questionnaire and 10 completed the post. ANCOVA was again selected to assess treatment effects. Teacher score on the pre-views questionnaire was used as the covariate in the analysis. We used the following model: change = pre score + treatment. Only those teachers who completed the pre and post-questionnaire were included in the model.

Changing Intentions to Teach Science as Inquiry and about NOS

We reviewed responses to items on the post-questionnaire, completed by every teacher, and post-interviews (see Appendix 1), conducted with a subset of teachers, approximately a month after the summer institute once the school year had begun. We looked for evidence of reflective comments where teachers linked new knowledge to their classroom teaching practice. First, we carefully read through each of the post-questionnaires and post-interviews. Two categories of reflective comments emerged from the data: (1) Teachers identified aspects of their former teaching that were not congruent with what they had learned in the summer session, and (2) Teachers described how they would need to change their teaching to be more congruent with what they learned in the PD. We then re-read each of the post-questionnaires and post-interviews separately, coding for the two aforementioned categories. When there was a question whether or not a comment fit in the category the final decision was reached by consensus. After reflective comments were categorised, we looked for evidence that reflection might lead to gains in knowledge and changes in teaching practice.

Results

Analyses of the pre–post knowledge and views instrument revealed that during the course of the summer institute participant teachers significantly deepened their subject matter knowledge and views of inquiry and NOS. During the same time period there was no significant change in comparison teachers' subject matter knowledge or views (see Figures 1 and 2).

Influence on Subject Matter Knowledge

Analyses of pre–post assessments revealed that participant and comparison teachers' knowledge increased from the beginning to the end of the summer institute, but to different degrees. Participant teachers entered the programme with higher scores than their comparison teachers (Participant: $M = 29.00$, SD = 13.84, $N = 18$; Comparison: $M = 22.33$, SD = 13.95, $N = 15$). This was not surprising given that participant teachers may have had more investment in the programme than

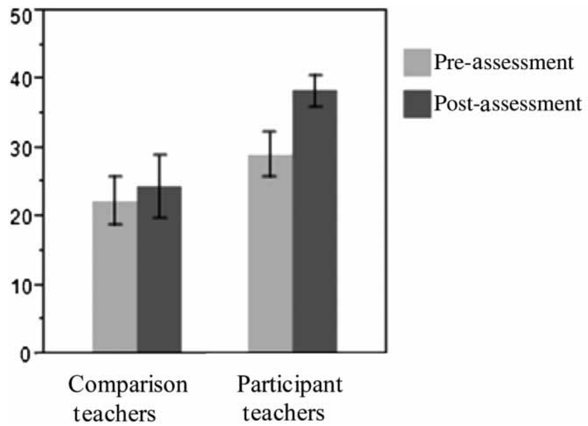

Figure 1. Mean subject matter knowledge pre–post assessment scores for comparison teachers (pre: $n = 15$, post: $n = 11$) and participant teachers (pre: $n = 18$, post: $n = 18$). Error bars were constructed using one standard deviation from the mean

comparison teachers. After participating in the programme participant teachers scores increased substantially whereas comparison teachers' scores increased only modestly (Participant: $M = 38.39$, SD = 9.79, $N = 18$; Comparison: $M = 24.36$, SD = 14.99, $N = 11$). Results from ANCOVA, compensating for the difference in pre-programme score, indicated the relative change of the treatment and comparison groups were significantly different statistically ($t = -2.94$, $p < 0.01$), as shown in Table 4. Fossil Finders teachers scores increased by 32% whereas comparison scores increased by only 11% over the same period of time. The slight gains observed in comparison teachers' scores might be explained by test–retest effects. That is, having already seen the questions on the pre-assessment, many of the comparison teachers may have thought more deeply about them or perhaps even looked up

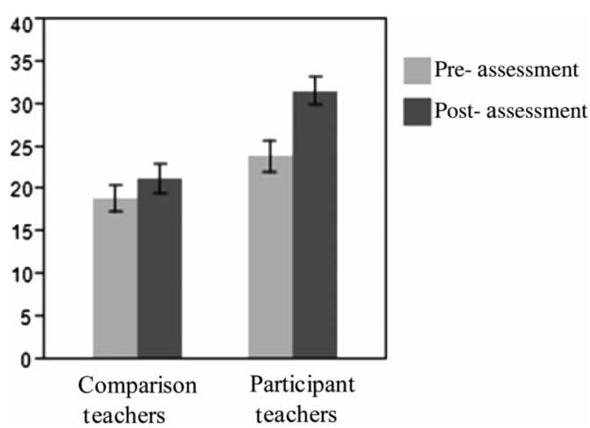

Figure 2. Mean views of inquiry and NOS pre–post assessment scores for comparison teachers (pre: $n = 15$, post: $n = 10$) and participant teachers (pre: $n = 18$, post: $n = 17$). Error bars were constructed using one standard deviation from the mean

Table 4. Results from ANCOVA for teacher subject matter knowledge using teacher score on the pre-content knowledge assessment as the covariate

	Estimate	Std error	*t*-Ratio	*p*-Value
Intercept	10.21	3.53	2.89	0.0076*
Pre	−0.36	0.11	−3.12	0.0044*
Treatment	9.52	3.24	2.94	0.0068*
r^2	0.31			

information related to the items. The 32% increase in the project teachers' subject matter knowledge after a week-long PD was substantial. In particular, participant teachers exhibited the most improvement on items related to geologic concepts they worked on during the summer institute, including items related to the principle of superposition, organism identification, and fossilisation. Participant teachers also made gains on an item related to populations and ecosystems. Generally speaking, we observed greater changes for teachers who entered the programme with limited subject matter knowledge and lesser changes for those who entered the programme with more subject matter knowledge. For example, teachers who scored below 30 points on the pre-assessment had a mean change of 18 points on the post-assessment, whereas teachers who scored above 30 points on the pre-assessment had a mean change of only 2.5 points on the post-assessment.

Influence on Views of Inquiry and NOS

Analysis of the pre–post online questionnaire reflected a range of understandings of inquiry and NOS across participant and comparison teachers (see Figures 3 and 4). Both groups began with fairly limited views of inquiry and NOS (Participant: $M = 23.90$, SD = 7.92, $N = 18$; Comparison: $M = 18.86$, SD = 6.07, $N = 15$). Similarly to subject matter knowledge, participant teachers held slightly more informed views on inquiry and NOS than their comparison teachers prior to their participation. This was not surprising given that participant teachers may have had more investment in the programme than comparison teachers. After the summer institute, participant teachers scores increased substantially, whereas comparison teachers scores increased only modestly (Participant: $M = 31.59$, SD = 6.60, $N = 17$; Comparison: $M = 21.20$, SD = 5.43, $N = 10$). Results from ANCOVA, compensating for the difference in pre-programme score, indicated the relative change of the treatment and comparison groups were significantly different statistically ($t = -4.46$, $p < 0.001$), as shown in Table 5. Fossil Finders teachers scores increased by 31% whereas comparison scores increased by only 8% over the same period of time. The 31% increase in views of inquiry and NOS after a week-long PD was substantial, whereas the slight gains in comparison teachers' scores might be explained by test–retest effects. The largest gain by a comparison teacher, Patty, was equal to the average amount of change for participant teachers. However, the remaining comparison teachers

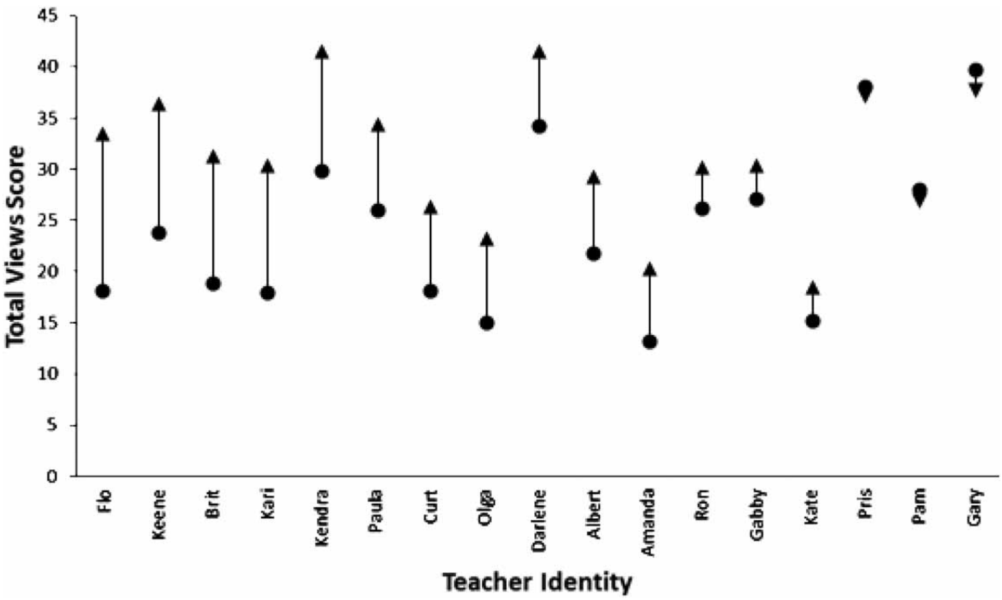

Figure 3. Participant teachers' views of inquiry and NOS before and after the summer institute measured by the views questionnaire. The point represents the pre-views score and the arrow represents change. Only participant teachers who completed the pre- and post-questionnaire were included in this figure

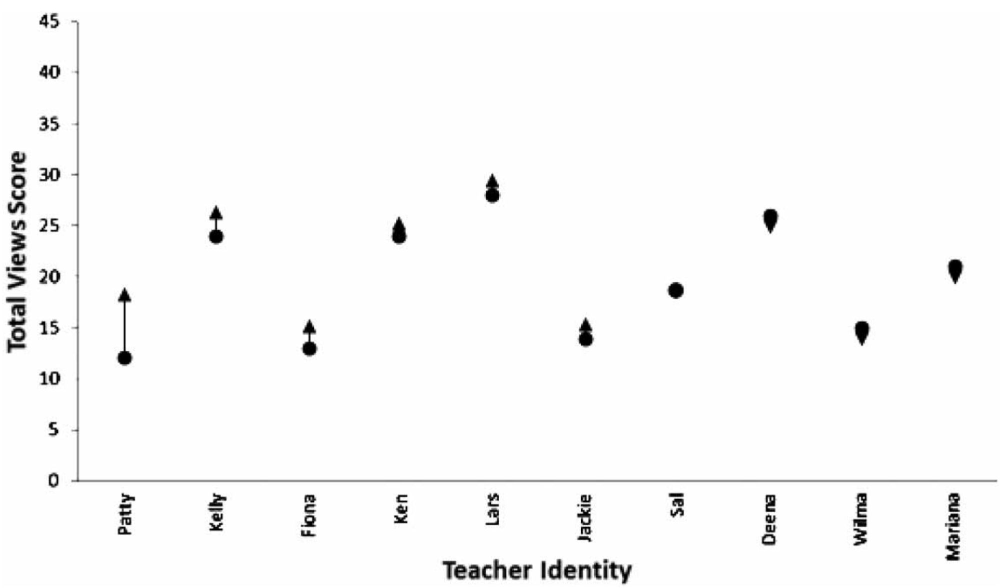

Figure 4. Comparison teachers' views of inquiry and NOS before and after the summer institute measured by the views questionnaire. The point represents the pre-views score and the arrow represents change. Only comparison teachers who completed the pre- and post-questionnaire were included in this figure

Table 5. Results from ANCOVA for teacher views of inquiry and NOS using teacher score on the pre-content knowledge assessment as the covariate

	Estimate	Std error	*t*-Ratio	*p*-Value
Intercept	8.28	2.46	3.37	0.0025*
Pre	−0.34	0.11	−3.16	0.0043*
Treatment	7.37	1.65	4.46	0.0002*
r^2	0.45			

showed very little change in their views of inquiry and NOS between the pre and post-questionnaires. Below we describe changes in teachers' views of inquiry and NOS from the pre to post-questionnaire.

Pre-views of inquiry. Of the inquiry related questions participant and comparison teachers scored lowest on pre-questionnaire items that asked them to define inquiry-based instruction and to describe what it might look like in their classrooms (see items 4.1 and 4.2 in Appendix 1). The mean score for participant teachers was 0.6 on item 4.1 and 0.7 on item 4.2. Mean scores for comparison teachers were 0.3 and 0.8, respectively. Eighty per cent of teachers scored in the naive and emerging categories on these items. Most teachers defined inquiry as hands-on or discovery-based learning. A typical naive pre-programme definition of inquiry-based instruction was illustrated in Jackie's pre-questionnaire response. She referred to inquiry as, 'Hands on, able to ask questions and then work together to solve the answers' (Comparison teacher, 8-2-09). Only five teachers between both groups scored in the informed or robust categories on their pre-questionnaire definition of inquiry. These teachers went beyond describing inquiry as hands-on and gave responses that were congruent with the essential features of inquiry. Further, they recognised that there were variations on inquiry such as the amount of guidance provided by the teacher. One of these teachers defined inquiry as, 'The process of understanding scientific principles through engaging in questioning, experimenting and data collection to draw conclusions' (Kelly, comparison teacher, 7-22-09). Teachers scored the highest on an item that asked them to describe the benefits of inquiry-based instruction (item 5) and another item where they were asked to describe how confident they were in teaching science as inquiry (item 7). Over 75% of participant and comparison teachers recognised that inquiry-based instruction had the potential to increase student engagement and over 80% of participant and comparison teachers reported that they felt fairly confident in their ability to teach science as inquiry.

Post-views of inquiry. Post-questionnaire results indicated that participant teachers greatly enhanced their views of inquiry. This was particularly the case on items 4.1 and 4.2. We observed no corresponding increase in comparison teachers' scores on these items. The mean score for participant teachers on items 4.1 and 4.2 increased from 0.6 to 1.5 and from 0.7 to 1.4 moving from the naive to the emerging category. After the institute, approximately 50% of participant teachers held informed or robust views on inquiry, up from 20% before the institute. These teachers recognised the importance of using data to answer scientifically oriented questions and could articulate what inquiry-based instruction should look like in their classrooms. For example, Kendra came to the summer institute thinking inquiry was,

> Allowing students to learn through seeking out answers. This also means that a teacher may have to work at building and fostering curiosity within units of study throughout the year so students have a desire to seek out answers. It means that students will learn to chase their curiosity in the classroom in the hopes they will continue to do so outside the classroom. (Participant teacher, pre-views questionnaire, 8-1-09)

After leaving the institute Kendra demonstrated a more informed view of inquiry, as illustrated below:

> Students are actively seeking to answer a scientific question in class. They will work to answer this question by recording data and analyzing their results. Finally, the students will communicate their findings in some way to the class. (Participant teacher, post-views questionnaire, 9-7-09)

Participant teachers also made gains on an item that asked them to distinguish between classroom inquiry and inquiry practised by scientists as well as on an item that asked them to describe how a palaeontologist might investigate how climate changed in an area throughout the past. However, these increases were not as substantial as the gains observed on items 4.1 and 4.2.

Pre-views of NOS. Participant and comparison teachers' NOS scores were slightly higher than their inquiry scores on the pre-questionnaire. The lowest pre-questionnaire scores on NOS items were on items 8, 9, and 13 (see Appendix 1). Nearly 75% of participant teachers, and even a greater number of comparison teachers, scored in the naive and uninformed categories when responding to items 8 and 9. These teachers viewed science as mainly experimental and thought of the scientific method as a procedure that most scientists followed in one way or the other. A naive response for item 9 described the scientific method as a step-by-step procedure. For instance, Caelyn said, 'In general, I believe (I hope) most scientists use the scientific method. I believe it is a practical, step-by-step way to reach a scientific, evidence-based conclusion' (Participant teacher, pre-views questionnaire, 7-28-09). Only about 30% of participants and comparison teachers were able to describe the relationship between theories and laws at the informed or robust levels. These teachers recognised theories as explanatory and laws as descriptive. The remaining teachers viewed the relationship between theories and laws as hierarchical; that is, well-tested theories could eventually become laws. For example, Ken stated, 'A scientific theory is a step below a law. A scientific law is a theory that has undergone rigorous testing and has always proven true' (Comparison teacher, pre-views questionnaire, 7-25-09). Of those items related to NOS, teachers scored the highest on an item that asked them to describe the difference between observations and inferences (item 11) and an item that asked them to discuss if and how the work of scientists is influenced by society (item 15). Nearly 90% of participant teachers and 100% of comparison teachers were able to adequately describe the difference between observations and inferences. Moreover, 100% of participant teachers and nearly 90% of comparison teachers recognised that social norms, socio-cultural issues, and political issues influence science.

Post-views of NOS. We observed a marked post-assessment increase in participant teachers' understanding of NOS. This was especially true on items 9, 12.1, 13, 14, and 16. Comparison teachers' views improved on items 9 and 12.1, but their gains were not quite as large as those of participant teachers. The mean score for participant teachers on item 9 increased from 1.0 to 1.6. Many of these participant teachers demonstrated a better understanding of the NOS tenet that scientists use multiple methods, depending on what question is asked. We also observed an increase in teachers' understandings of theories and laws and how they related to one another. The mean score for participant teachers increased from 1.4 to 1.9 on item 12.1 and from 0.5 to 1.5 on item 13. Many more participant teachers than comparison teachers developed an understanding about theories and laws: that theories are not just hunches, but explanatory frameworks based on multiple observations, whereas laws are descriptive statements that define observable phenomena. Furthermore, most participant teachers demonstrated an understanding that theories do not become laws, a common misconception that many teachers held, prior to the institute. For example in the pre-test, Keene stated,

> I think a law is a glorified theory. Laws, like Newton's Laws, are theories that have stood the test of time and of new data. Even though they're called laws, they still can't be proven. (Participant teacher, pre-views questionnaire, 7-22-09)

After the summer institute, her view had changed as illustrated below:

> A scientific law defines what will happen while a theory explains why it happens. The law of gravity tells us how an object will behave when dropped but doesn't get into the reasons why it behaves that way. The 'why' is left to theories on the curvature of space and time caused by mass. (Participant teacher, post-views questionnaire, 8-21-09)

Participant teachers also made gains on two items, one about the role of creativity in science (item 14) and another about how scientists can reach different conclusions using the same data (item 16). After participating in the summer institute, 94% of participant teachers held informed or robust views on item 14 (up from 67%) and 72% of participant teachers held informed or robust views on item 16 (up from 28%).

Changing Intentions to Teach Science as Inquiry and about NOS

One of the most interesting aspects of our findings was the presence of reflective comments made by participants centred on changing their intentions to teach science as inquiry and about NOS. A total of six different teachers made reflective comments following the summer session. Five of the six teachers made reflective comments on the post-views questionnaire, five made reflective comments during their post-interview, and four made reflective comments on both the post-views questionnaire and during their post-interview. As noted earlier, reflective comments fell into two categories that will now be described, followed by evidence that reflection may have led to enhanced knowledge and changes in practice for some teachers.

Reflection on former teaching. Five teachers identified aspects of their former teaching that were not necessarily congruent with what they learned during the summer institute. For example, Olga a fifth-grade teacher recognised how a lesson she taught before the programme fell short of being inquiry, because she did not have her students explain what they were doing. She shared,

> I probably look at them [her lessons] more now as hands on experiments because children were definitely engaged and children were definitely exploring, but I don't think I took it to the level of explanation like I should've or I could've . . . because I had the PD, it makes you reflect a little more on what you're doing and I think that's what all PD should do . . . I think there's always room for improvement and I'm not saying it's going to be the best but I do think that I've learned that you do have to take a look at what you're doing and what you're saying. (Participant teacher, post-interview, 10-4-09)

This comment shows that Olga was clearly connecting what she learned during the summer institute to her teaching practice, prior to participating in the programme. Interestingly, after the summer institute Olga and several other teachers started to equate inquiry with the 5E Learning Cycle (Engage, Explore, Explain, Elaborate, and Evaluate). Olga felt the 5E Model was too complicated for her students; therefore, instead of 5Es she adopted a 3E Model. Equating inquiry with the 5E Model may or may not be helpful in carrying our inquiry, because a teacher could easily have her students engage, explore, explain, elaborate, and evaluate outside of the context of a scientifically oriented questions, and without students giving priority to data. Olga did, however, recognise that many of her previous lessons were lacking a part where her students explained what they were observing, which is a very important component of inquiry.

Another teacher, Kendra, who taught seventh grade students made multiple reflective comments about her pre-institute teaching. She did this both on her post-questionnaire and in her interview. In one of her comments, she noted how her realisation came about. Kendra explained, 'We did the readings and we talked about inquiry, and I realised in many ways I was close and I was doing some things that were similar to inquiry, but not full on inquiry' (Participant teacher, post-interview, 9-28-09). Participating in the summer institute helped Kendra realise that many of the things she thought were inquiry were better characterised as hands-on teaching. She shared, 'I think I was doing a lot of hands-on science teaching before, but didn't necessarily have all of the aspects of inquiry' (Participant teacher, post-interview, 9-28-09).

Intent to change teaching. Four teachers described how they would need to change their teaching to be more congruent with what they learned in the PD. Albert shared the following:

> I feel pretty confident in adapting inquiry into the project that I have worked on with students in the past . . . we might use a nearby lake as a means to investigating ecosystems. We would ask, 'How are these creatures dependent on one another?' We would then survey the populations, make our predictions, spend some time observing and then check the scientific literature on these different critters. (Participant teacher, post-views questionnaire, 8-25-09)

Not only did Albert express his intent to change his teaching, but he also described how he might change a lesson to be more congruent with aspects of inquiry he learned during the summer institute. The next two excerpts come from teachers who both reflected on their former teaching in light of what they learned in the summer institute and discussed how they would need to change their teaching practice. Kendra shared that her instruction before the institute was not inquiry and now recognised that she would need to make some revisions to her instruction.

> I'm confident in my ability to teach science as inquiry. I have been using hands-on activities since I began teaching. Revising my activities to become inquiry activities will take a little bit of time and thought, but it will be time and thought well spent. (Participant teacher, post-views questionnaire, 9-7-09)

Another teacher, Brit, realised that she had not been emphasising aspects of NOS in her instruction and mentioned this was something she would change.

> I guess you know when we did it I thought well yeah, but how much do I emphasise it with my students, probably not enough. You know we think that okay, here is a scientist and they said that and case closed, let's move on. So that's really a key point to I think emphasise with my students. (Participant teacher, post-interview, 9-21-09)

We did not see evidence of reflective comments in the other 12 teachers' post-questionnaires or interviews. In some cases, the lack of critique or reflection may be explained by the fact that the teacher already held fairly robust views of inquiry and NOS (e.g. Darlene, Pris, Gary, and Paula) and may have already been teaching science in this way. However, in most cases, the lack of reflection was likely due to the fact that the teachers' understanding of inquiry and NOS were insufficient to allow them to effectively reflect on their pre-institute teaching. Prior to the summer institute, many of the teachers claimed they were confident teaching science as inquiry, even though we observed that their views on inquiry were quite limited. Following the summer institute, many teachers maintained that their pre-institute instruction was inquiry-based, even though there was no evidence for this. For example, Amanda, a fourth to eighth grade science teacher believed her pre-programme instruction was inquiry-based. When asked about her teaching after the summer institute, she adopted a relativist view of inquiry (i.e. inquiry is in the eye of the beholder) writing,

> Inquiry means different things to different people. What might be inquiry to me, might not be inquiry to someone else. However, I feel comfortable teaching it with my own understanding. I think that students learn best, hence the reason I use it. However, I use it in different degrees and forms depending on the concept at hand. (Participant teacher, post-views questionnaire, 8-31-09)

Because her views on inquiry were still insufficient, she was unable to critique her pre-programme instruction and retained the belief that her teaching was inquiry-based.

Evidence that reflection may lead to enhanced knowledge and practice. Interestingly, the teachers who made reflective comments on post-views questionnaires and interviews also demonstrated some of the greatest gains in their views on inquiry and NOS scores. The mean increase for all participant teachers on the views questionnaire was 7.4, whereas the six teachers who made reflective comments had a mean score of 11.2 (SD = 5.4). This suggests that the act of reflective thinking may result in teachers having greater gains in knowledge, than if they did not engage in this kind of reflection. Furthermore, five of the six teachers who made reflective comments also described actual changes to their teaching practice on the post-questionnaire and/or interviews, whereas none of the other teachers described changes to their teaching practice. For instance, in her questionnaire Pam wrote,

> Since my experience at Fossil Finders, I have changed the way I approach science education. I present the students with a problem and allow them to question, discuss, and solve it. Classroom inquiry should mirror scientific inquiry. Students describe objects and events, ask questions, construct explanations against current scientific thinking and communicate and defend their ideas with others. (Participant teacher, post-views questionnaire, 9-5-09)

Here, Pam discussed actual changes she made to her teaching practice based on her experience in the summer institute. It appears that through her participation in the institute, Pam was able to assess her former teaching and make changes to the approach. Several other teachers also explicitly discussed how reflection on their former teaching resulted in actual changes in their teaching practice. In her interview, Flo said,

> Until I participated in Fossil Finders, I always enjoyed asking questions and having them answered right away. During the PD you guys always asked, 'What do you think?' I am taking that approach a whole lot more and letting the children start to develop their own thoughts and ideas and impressions before I just give out the answer like I had in the past. Letting their minds just grow ... Before I thought they were curious and being able to share that knowledge with them would satisfy their quest for knowledge. But by doing that, yeah, they got the knowledge, but they didn't get to develop their imagination or develop that level where they have to think things through or come up with a logic or reasoning behind it. I think this is as important as having the right information. (Flo, participant teacher, post-interview, 9-22-09)

Flo realised that turning questions back on her students, a practice used by the instructors in the summer institute when she asked questions, might promote deeper thinking in her students. Therefore, instead of answering her students' questions right away, as was her custom before the summer institute, Flo stated she had begun to incorporate this questioning technique into her own teaching. Flo made the powerful reflection that by giving her students the chance to think about their own questions, they 'get to develop their imagination or develop that level where they have to think things through or come up with a logic or reasoning behind it'. Using logic and imagination aligns with what scientists do in developing explanations based on data, and it is an important outcome of inquiry-based teaching.

Another teacher, Kendra, reflected on how her teaching before the institute included hands-on activities, but that her instruction was not quite inquiry. Kendra discussed how she had already changed some of her classroom instruction, based on what she had learned in the institute. She said,

> I think previous to coming to Fossil Finders I knew I was doing activities in my class but I didn't realise that I wasn't quite doing inquiry. So, I was having students . . . be active in class and have things at their table and manipulate things at their table, even collecting data, but not really having them do inquiry. Not really giving them a question to answer, um not even kind of closed inquiry. So I think I got more of a clarification of what inquiry is. I have been able to do a little bit of this in my class already. (Kendra, participant teacher, post-interview, 9-28-09)

Although these comments were reported by teachers and not directly observed, it was interesting that comments about actual change were only reported in those cases in which teachers made reflective comments in post-questionnaires and interviews. Beyond making reflective comments, these teachers shared no other commonality that we are aware of (see Table 1). This suggests that reflection may be an important step in teacher change.

Discussion and Conclusions

The Fossil Finders PD programme was designed to support teachers in learning about geology, evolutionary concepts, NOS, and scientific inquiry; with the hope they would later translate this knowledge into their teaching. Although this study took place within the context of an authentic geologic investigation, the investigation was merely a vehicle to engage teachers in deep learning about subject matter, inquiry, and NOS. We believe this model could be useful in other science contexts. For example, PD designers could switch out the fossil investigation with an authentic study of an ecological problem in order to promote learning of subject matter, inquiry, and NOS. Findings from this study indicate that relatively short, yet intensive and well-designed PD experiences can result in substantial increases in teacher subject matter knowledge and views of inquiry and NOS by engaging teachers in an authentic scientific investigation. Important aspects of the PD include providing pedagogical support and assisting teachers in connecting their own learning with their classroom teaching. Finally, there is also some indication that this kind of PD has the potential to support teachers in linking new knowledge with their future classroom teaching practice.

Influence on Subject Matter Knowledge

Gains in subject matter knowledge were most pronounced for those teachers who entered the programme with limited prior knowledge. This was not surprising, given these teachers had greater potential for growth than those who entered the summer institute with more subject matter knowledge. Nonetheless, it was promising to see that teachers with limited subject matter knowledge were able to enhance their knowledge in a short period of time through an inquiry-based experience. This suggests that situating teacher learning in an authentic investigation and supporting them in thinking about how they could translate newly acquired scientific knowledge into the context of their classrooms can be effective in enhancing teacher subject-matter knowledge. These findings related to teacher learning concur with Minner, Levy, and Century's (2010) findings about student learning, mainly that engaging students in investigations has been associated with enhanced student content learning. Furthermore, these findings support the assertion that it is possible to effectively learn subject matter knowledge through inquiry (e.g. Anderson, 2002; Geier et al., 2008; Hmelo-Silver, Duncan, & Chinn, 2007; Shymansky, Kyle, & Alport, 1983) and highlights the importance of engaging teachers in learning experiences similar to those they will be expected to enact in their classrooms (Garet et al., 2001; Loucks-Horsley et al., 2003).

Influence on Views of Inquiry and NOS

We expected to see the greatest gains in views of inquiry and NOS scores in those teachers who held very limited views of inquiry and NOS (as we did for subject matter). Other studies have shown results of this nature (e.g. Schwartz et al., 2004). However, this was not the case. For example, Kendra, who entered the programme with fairly informed views of inquiry and NOS made large gains, while Kate who entered the programme with limited views of inquiry and NOS made only modest gains. In general, gains in views were most pronounced for those participants who entered the programme with moderate understandings of inquiry and NOS, as opposed to those who entered the programme with limited understandings. We find this result most interesting, and it may imply that there is some threshold of understanding related to inquiry and NOS that an individual must acquire before greater changes in views can occur. This is similar to the findings of Capps and Crawford (2010) who observed that two teachers who entered a PD programme with very limited views of inquiry and NOS made only modest gains in their views where a teacher who entered the programme with a stronger foundation made more pronounced gains. Perhaps longer term PD may be needed for those teachers who have not reached this threshold. Inquiry and NOS are abstract, multifaceted constructs and may, therefore, be more difficult to grasp (Crawford, 2000, 2007; Lederman, 1999) and will likely require much more support.

Another interesting point is that the majority of participant and comparison teachers entered the programme expressing confidence in their ability to teach science as inquiry, even though their conceptions of inquiry did not align with ideas put forth by the *National Science Education Standards*. This confirms other researchers' concerns that there is a great deal of confusion between what teachers understand about inquiry-based instruction and how inquiry is defined in reform-based documents. Left unchecked, the initial confidence, or self-efficacy, that many appeared to have about these teaching approaches would likely result in a lack of change in views, as was the case for Brenda and Hank in the study by Schwartz et al. (2004). In the Schwartz et al. study, these two preservice teachers had a lot of confidence in their initial views and because of this, saw no need for change.

Changing Intentions to Teach Science as Inquiry and about NOS

In order for teachers to enact reform-based practices in their classrooms, they need adequate subject matter knowledge as well as an understanding of inquiry and NOS (Lederman, 1999; Luft, 1999; Shepardson & Harbor, 2004). Overall, most of the participant teachers in this study made gains in their subject matter knowledge and views of inquiry and NOS. Some made great leaps, whereas others' gains were more modest. Gains in knowledge may be necessary, but not sufficient to effect real change in one's teaching practice. There are many other factors that influence classroom teaching practice (Shepardson & Harbor, 2004). One such factor suggested in the literature is teacher reflection (Dewey, 1933; Loughran, 2002; Schön, 1983, Windschitl, 2003). Although not the case for every teacher, there was evidence suggesting that the ability to connect knowledge to practise through reflection may lay the ground work necessary for actual changes in one's practice. During the PD, we actively supported participant teachers in articulating their views on inquiry and NOS, and we assisted them in comparing their views and teaching practice to images of inquiry and NOS in the literature. This process, along with completing the questionnaires and participating in interviews, appeared to be influential in supporting some teachers in thinking more deeply about how their views of inquiry and NOS related to their classroom practice. We have evidence that six teachers clearly recognised inconsistencies between their pre-programme views and instruction, and what they learned during the PD. Not surprisingly, these were some of the teachers who also made the greatest gains in their views of inquiry and NOS after the summer institute. Furthermore, five of these teachers reported changing their teaching practice based on their new knowledge. These findings highlight the importance of teachers' use of reflective thinking, as described by Dewey, or engaging in *active reflection* which may serve to enhance teacher knowledge (Dewey, 1933; Loughran, 2002; Schön, 1983). Active reflection may be a significant intermediary step in changing one's classroom teaching practice. We suggest future studies investigate the role reflection may play in laying the foundation for changes in teacher practice related to inquiry.

There are several limitations of the study that need to be addressed. For example, there was a lack of established initial equivalence between the participant group and the comparison group. This methodological limitation is common in non-experimental studies in education research. In order to minimise the lack of equivalence we asked participant teachers to select comparison teachers with a similar background and student population. Another limitation relates to test–retest effects. Because the same assessment was given to participant and comparison teachers before and after the summer institute it was possible that teachers could have learned from the assessment. Although there were slight gains in comparison teachers' post-assessments, the change was not significant, whereas we observed significant change for participant teachers. A third limitation was that we employed teacher self-report in order to discuss teachers' intent to change and actual change in teaching practice. Thus, we cannot know for sure if these changes actually did occur, or if the teachers discussed these changes in order to please us since reporting on actual classroom practice was beyond the scope of this particular study. In a related study, we will follow several participant teachers into their classrooms after the PD in order to understand how the PD experience impacted their classroom teaching practice.

In summary, our first conclusion is that relatively short-term, yet intensive, well-designed PD experiences that engage teachers in an authentic investigation can effectively enhance teachers' subject matter knowledge. As expected, we observed the greatest gains for those teachers who entered the summer institute with limited subject matter knowledge. Large gains for teachers with limited subject matter knowledge points to the critical need for well-designed PD experiences that engage teachers in sense making through authentic learning experiences and supports them in translating newly acquired scientific knowledge into the context of their classrooms. Our second conclusion is that short-term, yet intensive and well-designed PD experiences that integrate inquiry and NOS and subject matter, align with school content objectives, and model reform-based instruction, can effectively enhance teachers' views of inquiry and NOS, with a caveat. In this study, those teachers with limited knowledge of inquiry and NOS did not demonstrate as large gains as some of the teachers who entered the programme with greater understandings of inquiry and NOS. This suggests that having a basic level of foundational knowledge related to inquiry and NOS may serve as a launching point to acquiring deeper knowledge related to inquiry and NOS. We did not explore what the actual threshold might be, but suggest this as an area for further investigation. Teachers come to PD programmes with varying backgrounds, and professional developers may need to stratify PD experiences for teachers, depending on their initial levels of understandings. Our third conclusion is that active reflection on one's views and teaching practice can help to solidify new knowledge and assist in anchoring this knowledge in one's teaching practice. In this study, teachers who actively reflected on their views and teaching practice made the greatest gains in their views of inquiry and NOS scores after the summer institute. Many of these teachers also identified the intent to change their teaching practice and some teachers provided evidence of how they had already changed their practice, based on what they learned in the PD.

Implications

Results from this study have some important implications for teacher PD. First, our findings suggest that well-designed PD that engages teachers in authentic investigations and supports them in reflecting on their teaching practice might be an effective way to promote teacher understanding and eventual use of reform-based teaching. Second, although some teachers might appear to make large strides towards reform-based teaching in relatively short periods of time, this will not be true for all teachers. The fact that not every teacher made large gains in their views of inquiry and NOS and in thinking about changes to their practice highlights the need for high-quality PD that extends beyond the initial PD work session. Some teachers will need more time and support to articulate these difficult concepts and assimilate them into their understandings and, eventually, into their practice. Finally, the fact that many of the teachers who entered this programme with uninformed views of inquiry and NOS made significant gains in their views after the rich, week-long experience, suggests a similar approach might be fruitful in supporting preservice teachers in enhancing their views on inquiry and NOS. A short-term, but intensive experience that engages preservice teachers in scientific practices and encourages consideration of aspects of NOS might offer learning opportunities generally not afforded in the traditional college science course or traditional science teaching methods courses. This kind of authentic science experience, integrated with subject matter, inquiry-based methods, and strategies for teaching about NOS has potential to transform preservice science teacher education experiences.

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Appendix 1. List of instruments

- Rutledge, M.L., & Warden, M.A. (2000). Evolutionary theory, the nature of science & high school biology teachers: Critical relationships. *The American Biology Teacher*, 62(1), 23–31.
- Libarkin, J.C. (2008). *GCI Concept Inventory: GCI v.2.1.1*.
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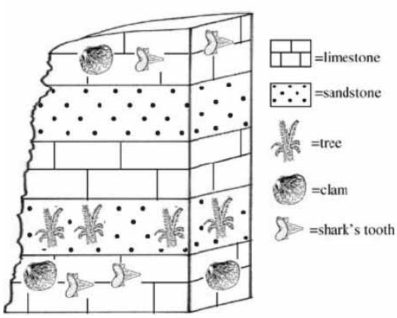
Selected items from the 24-item written subject matter knowledge assessment

15. What assumptions do geologists make as they study Devonian Period rocks to begin to understand the biotic, environmental, and tectonic history of an area? Please select all statements that apply.

A. Processes such as weathering, erosion, and sedimentation occurred at exactly the same rates in the Devonian Period as they do now.
B. Processes such as weathering, erosion, and sedimentation acted according to exactly the same physical laws in the Devonian Period as they do now.
C. The chemistry of the ocean and atmosphere were exactly the same in the Devonian Period as they are now.
D. Genetics followed exactly the same chemical principles in organisms reproducing and evolving in the Devonian Period as they do now.
E. World climate was exactly the same in the Devonian Period as it is now.
F. The principles of how water interacts with pure quartz sand to form ripples and scours was exactly the same in the Devonian Period as it is now.

22. The illustration below represents a series of rock layers from a specific geologic work site.



Based on this illustration, please describe what might have occurred through time at this site in order for these rock layers to have formed and for these fossils to have been preserved.

17-item open-response views questionnaire

1. How would you describe your role as a science teacher?
2. Describe the predominant teaching strategies you use and explain why you use them.
3. How do students learn science best?

Current reform documents in science education call for teaching 'science as inquiry'.

4.1. What does this mean?
4.2. How might inquiry-based science teaching look in your classroom?
5. Do you think there are benefits to using inquiry-based science instruction?
- If so, why and what are the benefits?
- If not, why not?

6. How might classroom inquiry compare to scientific inquiry?
7. How confident are you in your ability to teach science as inquiry? Please explain your answer.
8. Does science always involve doing experiments? Please explain your answer.
9. What is the scientific method?
Do all scientists use the scientific method? Please explain your answer.
10. What does the word *data* mean in science?
Is *data* the same as or different from *evidence*? Please explain your answer using examples.
11. Are *observations* the same as or different from *inferences*? Please explain your answer using examples.
12.1. What is a scientific theory?
12.2. After scientists have developed a theory, does the theory ever change?
- If yes, what is the process by which a scientific theory may change?
- If no, please explain why scientific theories do not change.

13. Is there a difference between a scientific theory and a scientific law? Please explain your answer.
14. Is there a role for creativity and/or imagination in scientific investigations?
- If yes, then at which stage(s) (i.e. planning and design; data collection; after data collection) of an investigation might a scientist use imagination and creativity? Please explain your answer using an example.
- If no, please explain why not and provide an example.

15. Is the work of scientists influenced by society? Please explain your answer using an example.

Scientists think that about 65 million years ago dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two are widely supported. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago, beginning a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction.

16.1. How are these different hypotheses possible if both groups of scientists have access to and use the same data to derive their hypotheses?
16.2. Is it possible for two different scientists to perform the same scientific procedures and reach different conclusions? Please explain your answer.
17. Explain the process a paleontologist might use to research how climate has changed throughout the geological past in NY.

Semi-structured interview

1. What is your motivation for attending Fossil Finders?
2. How comfortable do you feel with teaching subjects like geology and evolution? Do you have any major concerns?
3. I see you have had (or not had) professional development related to scientific inquiry? Describe it. What did you learn? Has it influenced your teaching in any way? How?
4. I see you have (if not, skip question) had some science research experience? What did you do? Has it influenced your teaching in any way? How?
5. What does it mean to you to have an inquiry-based teaching approach?
6. In your application you describe a lesson (or unit) that . . ... Is this inquiry? If so, what are the aspects of the lesson that make it inquiry (What makes it inquiry)?
   -If not, can you describe for me an inquiry-based lesson? What are the aspects of the lesson that make it inquiry (What makes it inquiry)?
7. In the video clip you sent I saw . . .. . . Tell me about this clip. Why did you choose to send this clip? What is it demonstrating? Some people send their best, others send typical . . ... Which were you thinking when you sent this? If this is representative of your teaching? Why or why not? What would your most effective lesson look like, consider something you taught in the last year?
8. Are there times or situations where inquiry teaching is not a useful method? Tell me about these (Lotter et al., 2007).
9. What constraints do you feel you have to using inquiry-based science teaching (Lotter et al., 2007)?
10. Do your students ever generate their own questions to investigate? Can you think of an example? If not, do you ever give students questions to investigate? Can you think of an example? When you do have students investigate questions (theirs or ones you pose), how do you help them connect what they are studying with scientific knowledge?
11. Do you ever have students work with data? When your students collect data, what do they do with it? Prompts: Do they graph it? Do they use it as evidence? How? Can you give an example?
12. Do you ever have your students share their findings with others? If so, how does this work? Do you have students engage in discussion about their findings? What does this look like?