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Inquiry-based instruction in science classrooms: Is it happening?

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ABSTRACT

Anecdotal accounts from science educators suggest that few teachers are teaching science as inquiry. However, there is little empirical evidence to support this claim. This study aims to contribute to the documentation of the use of inquiry in classrooms. We examined the teaching practice as well as views of inquiry and nature of science (NOS) of a group of well-qualified and highly-motivated 5^{th}-9^{th} grade teachers prior to their participation and engagement in a National Science Foundation funded inquiry-based professional development program. We used a range of data sources, including program applications, classroom observations, videotape data, an open-response views-survey, and semi-structured interviews to assess teaching practice and views of inquiry and NOS. We also looked for relationships between teachers' views and their teaching practice. Findings indicated that most teachers held fairly limited views of inquiry-based instruction and NOS. In general, these views were reflected in their teaching practice. The majority of these teachers used primarily teacher-centered instructional practices. Elements of inquiry including *abilities*, *understandings*, and *essential features* were observed or described in less than half of the classrooms. Most commonly, teachers focused on abilities *to do* inquiry instead of the *essential features* of or *important understandings about inquiry*. This study documents that even some of the better prepared teachers struggle to enact reformed-based teaching and highlights the critical need for rigorous professional development to support teachers in learning about inquiry and NOS and enacting reform-based instruction in their classrooms.

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Introduction

Reform documents in science education advocate for teachers incorporating inquiry-based instruction into their teaching practice and teaching about the nature of inquiry and nature of science (American Association for the Advancement of Science, 1989, 1993; National Research Council [NRC], 1996; 2000; National Science Teachers' Association Position-Statement, 1998). Inquiry-based instruction is an important science teaching strategy that involves supporting students in investigating questions and using data as evidence to answer these questions (e.g. Crawford, 2000). Teaching through inquiry is thought to promote scientific literacy (Hodson, 1992) and has the potential to improve both student understanding of science and engagement in science (AAAS, 1989, 1993; NRC, 1996). Moreover, inquiry-based instruction provides a context to begin learning about the nature of inquiry and nature of scientific knowledge (Schwartz, et al., 2004). Unfortunately, most teachers have, "limited knowledge of, and experience with scientific inquiry, or the process by which scientific knowledge is generated. This puts serious limitations on their ability to plan and implement lessons that will help their students develop an image of science that goes beyond the familiar 'body of knowledge'" (Gallagher, 1991, p. 132). In order for teachers to enact inquiry-based instruction in their classrooms and begin teaching about nature of science (NOS) it seems reasonable that they will need to develop their own abilities to do inquiry, understandings about inquiry and NOS, and the pedagogical skills necessary to teach science as inquiry and about NOS.

Over the past several decades, there have been a variety of efforts to support teachers in enacting inquiry-based instruction, including curriculum interventions (e.g Blumenfeld et al., 1991; Krajcik, Blumenfeld, Marx, & Soloway, 1994; Ladewski, Krajcik, & Harvey, 1994) as well as pre-service (e.g. Crawford, 2007) and in-service professional development (e.g. Jeanpierre, Oberhauser, & Freeman, 2005; Lotter, Harwood, & Bonner, 2007; Luft, 2001). In general, these initiatives have shown that although inquiry-based instruction may be difficult, well designed programs can support teachers in learning about and using inquiry-based instruction in their classrooms (Anderson, 2002). Although science educators anecdotally report that teachers do not typically use inquiry-based approaches in their classrooms, in searching the literature we have found few empirical reports supporting this statement. The few studies or reports that document mainstream teaching practice related to inquiry include a series of case studies connected with project synthesis (Stake & Easley, 1978), classroom observations of science and mathematics teachers from the Inside the Classroom study (Weiss et al., 2003), and the TIMSS video study of Eighth-Grade Science teaching (NCES, 2006). Inquiry-based instruction was not the main focus of any of these studies. Outside of these, there is little information beyond survey data (e.g. US Department of Education, 1999) reporting on classroom practice related specifically to inquiry. Because of the lack of empirical evidence, many articles either cite these non-inquiry specific reports, resort to using anecdotal accounts when commenting on classroom teaching practice (e.g. Lord & Orkwiszewski, 2006; Radford, 1998; Wells, 1995), or cite anecdotal accounts of others (e.g. Windschitl, 2002). The aim of the present study is to investigate the practices and views related to inquiry and NOS of a group of highly-motivated and well-qualified teachers prior to their involvement in an inquiry-based professional development program. Specifically we asked:

1) What was the nature of teachers' instruction prior to participating in the program?
2) What were these teachers' views of inquiry and NOS?
3) What is the relationship between teachers' views of inquiry, NOS, and their teaching practice?

Theoretical Framework

Teaching Science as Inquiry

Classroom inquiry as described in reform documents includes three different elements. The first two are educational outcomes, and the third is a teaching strategy (NRC, 1996, 2000). First, inquiry can be thought of as a content area of study. In this way, learners should come to understand how scientists do their work. For example, students should understand that scientists ask questions, perform different types of investigations, and produce explanations based on their observations (NRC, 1996). *Understandings about inquiry* reflect the philosophical and socio-historical natures of scientific inquiry and NOS and thus there is some overlap between *understandings about inquiry* and NOS (see Table 4 for a list of the *important understandings about inquiry*). A second element of classroom inquiry is a student's ability to do scientific inquiry (NRC, 1996). This includes such aspects as asking and identifying questions, planning and designing experiments, collecting data using data, and connecting it with explanations (see Table 4 for a list of the *abilities to do inquiry*). Third, classroom inquiry can be viewed as a kind of pedagogy, or one's ability to employ inquiry-based instruction in the classroom in order to address key science principles and concepts (NRC, 2000). Inquiry as a science teaching strategy includes the five essential features of inquiry and their variations (see Tables 4 & 5 for a list of the *essential features of inquiry* and their variations). The variations on inquiry help to highlight who is initiating a given aspect of inquiry, for example, inquiries initiated by a teacher tend to be more structured, giving students less intellectual ownership, whereas inquires initiated by students tend to be more open, giving students more intellectual ownership. Although inquiry-based teaching is not the only way to teach science, it is important because inquiry instruction exposes students to a type of learning that parallels the work of practicing scientists, helping them develop deeper understandings of science and critical thinking skills. Moreover, inquiry-based instruction provides a fruitful context to address understandings about inquiry and NOS (Carey & Smith, 1993; Schwartz, Lederman, & Crawford, 2004).

The importance of NOS instruction is emphasized in reform-based documents (AAAS, 1989, 1993; NRC, 1996, 2000). NOS refers to an understanding of science as a way of knowing, including the values and beliefs fundamental to the development of scientific knowledge (Lederman, 1992). Although there is no agreed upon list including all aspects of NOS (Duschl, 1990) there is a general consensus in science education on aspects of NOS thought accessible in K-12 classrooms (e.g. Lederman et al. 2002; McComas et al., 1998). Included in this consensus are that students should understand science is: empirically based; tentative; a product of human imagination, inference, and creativity; subjective; socially and culturally embedded; and they should also understand the distinction between observations and inferences and the relationship between scientific theories and laws. 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; Ackerson & 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.

It is commonly believed that teacher knowledge affects classroom practice (Cochran-Smith & Lytle, 1999). Thus, the interaction between teacher knowledge and classroom practice related to inquiry and NOS is an important locus of study in science education. There are a variety of ways to conceptualize teacher knowledge. Two primary forms of teacher knowledge discussed in the literature are content knowledge and practical knowledge. Content knowledge, includes: knowledge of specific science subject matter (i.e. geology and evolution), knowledge about what scientific inquiry is (both as a process and what scientists do), knowledge about classroom inquiry (NRC, 2000), and knowledge about NOS. Practical knowledge comes from past experience and includes both knowledge and beliefs derived from one's teaching and learning experiences (Fenstermacher, 1994; van Driel, 2001). In considering classroom teaching practice related to inquiry, it is important to understand how both content knowledge and practical knowledge influence teachers' practice. As we better understand the interaction between these types of knowledge we will be better able to support teachers in learning about and teaching science through inquiry.

Method and Data Sources

We used a mixed methods approach consisting of quantitative and qualitative data from multiple sources (Creswell, 2009). Our study focused specifically on two groups of teachers recruited for a professional development program, Pilot Groups 1 & 2 (P1 & P2). The data used in this study were collected prior to teachers' engagement in a two-year, inquiry-rich professional development experience. The aim of this research was to characterize or profile participants' teaching practice related to inquiry and NOS, and determine their views of inquiry and NOS prior to participating in the professional development experience. We then looked for relationships between teachers' views and their teaching practice. Because a single lesson might not be representative of a teacher's classroom practice we used a number of data sources to gain a better understanding of the nature of these teachers' instruction. Data sources included application materials, videotape data and observations of classroom instruction, and an open-response survey of views on inquiry and NOS. Additionally we conducted interviews with a subset of the participants. Table 2 displays research questions and the corresponding data sources and analyses.

Table 2. Research questions with corresponding data sources and analyses

Question	Data Sources	Analyses
1) What was the nature of teachers' instruction prior to participating in the program?	• program applications • classroom observations/videotape data • selected questions from semi-structured interviews	• a priori codes based on evidence of aspects of inquiry, NOS, and if the lesson was teacher or student initiated
2) What were these teachers' views of inquiry and NOS?	• written survey (VNOS-C, VOSI, and additional items) • selected questions from semi-structured interviews	• modified 4-point rubric using coding criteria recommended by Lederman et al. (2002); developed additional questions drawing on elements of inquiry defined by INSES (NRC, 2000)
3) What is the relationship between teachers' views of inquiry, NOS, and their teaching practice?	• those listed above	• those listed above

Context of Study

This study took place during the initial stages of the National Science Foundation (NSF) funded project, Fossil Finders: Using Fossils to Teach about Evolution, Inquiry, and Nature of Science held in the northeastern part of the U.S. The primary goal of Fossil Finders was to develop materials and support teachers and their students in learning about NOS and evolutionary concepts through an authentic investigation aimed at understanding how sea life responded to changes in the environment during the Devonian Period in central NY. More than 120, 5th-9th grade teachers applied to the Fossil Finders program over a period of two years. From the applicant pool, a total of 30 teachers were selected to participate in the program. Ten New York State teachers were selected for the first cohort (2008-2010) and 20 other teachers, from across the country, were selected for the second cohort (2009-2011). Selection criteria included: quantity of college science courses taken, presence or absence of science research experience, teaching experience (years), quantity of science professional development, what they hoped to gain, their willingness to participate in the project, and evidence of a supportive school administration. These teachers were selected based on their outstanding credentials as well as their declared desire to improve their science teaching. Selected teachers had an average of 11 years of teaching experience, took nearly 12 college-level science courses, and had over three PD experiences in science. Moreover, most of the 7th-9th grade teachers were teaching classes in the discipline in which they received their degree. We suggest these teachers are perhaps some of the better prepared and motivated teachers from across the country (see Table 3 Appendix A for teachers' backgrounds).

Data Collection & Analysis

Characterizing the nature of teachers' instruction. We used information from program applications, classroom observations and/or videotape data selected by the participants, member-checking and semi-structured interviews to characterize teachers' practice. As part of the application process, we asked each applicant to describe a successful lesson or unit they taught in the last two years, in order to get an idea of what instruction might look like in their classrooms. After applicants were selected, we personally conducted classroom observations and/or requested video tape data of teachers' classroom instruction. We operated under the assumption that these highly-motivated, conscientious teachers would describe and record some of their better lessons, giving us a best case scenario of their classroom instruction. Complete data sets, including program applications, descriptions of lessons, and observations of lessons, were collected for 26 of the 30 participants. We analyzed these data sources looking for the presence of inquiry and NOS and who initiated the inquiry. We used our analyses to characterize the nature of each teacher's instruction. In analyzing the multiple data sources we used the highest score related to inquiry-based teaching, NOS, and who initiated the inquiry derived from any single data source for each of the 26 participants. For example, if a description of a lesson yielded a higher score than a classroom observation we used the higher score. Because we had a limited number of observations, we also conducted a semi-structured interview with a subset of the 26 teachers to corroborate our interpretations and gain a greater understanding of the nature of these teachers' instructional practices.

Presence of inquiry & NOS. In analyzing lessons and descriptions of lessons we used an *a priori* coding scheme looking for evidence of inquiry defined by the *National Science Education Standards* (NRC, 1996, 2000) and aspects of NOS reported to be accessible in K-12 classrooms (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). The codes were used to develop a numerical score based on the presence (1) or absence (0) of individual aspects of inquiry and NOS in teacher's lessons (see Table 4 for a complete list of codes). Because there is some overlap between the eight *abilities to do inquiry* and the five *essential features of inquiry,* that is, some of the *abilities* are incorporated into the *features* (e.g. the fourth *ability* (A4) has learners develop explanations using evidence, this is the same as the third *essential feature* (EF3) where learners use evidence to develop explanations)*;* we merged the *abilities* and *essential features of inquiry* into one category. In doing so, we ended up with a total of eight codes representing the *abilities to do* and *essential features of inquiry*. As a result of this merger, a teacher could receive a score from zero to eight for the presence or absence of *abilities* and *features* of inquiry in a lesson. Scores for *understandings about inquiry* and aspects of NOS could range from zero to seven since there were seven aspects of each. We also noted if *understandings about inquiry* and NOS were addressed explicitly or implicitly by teachers in the lessons. In situations where the presence or absence of aspects of inquiry or NOS was unclear, we spoke with the teacher for clarification and the final decision was determined based on the consensus of a group of science educators.

Who initiated the inquiry. To establish who initiated aspects of inquiry observed or described in teachers' lessons, we combined and modified table 2-6 from *INSES* (NRC, 2000) with the Inquiry Analysis Tool (Bell, 2002). In doing so, we created a matrix that could be used to describe if aspects of inquiry were either student or teacher-initiated. We used a numerical score between 1 and 4 to describe who initiated each of the *abilities* and *features* of inquiry observed or described in a lesson; 1 being the most teacher-initiated, and 4 being the most student-initiated (see Table 5). Thus, if a lesson included all eight *abilities* and *features of inquiry*, and they were completely student-initiated, the lesson would score 32-points, whereas a lesson with no aspects of inquiry would be scored as a zero. In situations that were unclear, the final decision on who initiated the inquiry was determined based on the consensus of a group of science educators.

Table 4. Elements of inquiry *(NRC, 1996, 2000)* and NOS (Lederman et al., 2002). These were used as codes to determine the presence (1) or absence (0) of aspects of inquiry and NOS in teachers' lessons

Important Abilities and Essential Features of Inquiry EF= Essential Feature A= Ability	**Important Understandings** U= Understanding	**Nature of Science** NOS= Nature of Science
EF1 (A1): Involved in sci-oriented problem	**U1:**Different kinds of questions suggest different kinds of scientific investigations	**NOS1:Tentative** or subject to change
A2: Design an conduct investigation	**U2:**Current scientific knowledge and understanding guide scientific investigations	**NOS2:Empirically based** (based on and/or derived from observations of the natural world)
E2: Priority to evidence in resp. to a problem: observe, describe, record, graph	**U3:**Mathematics is important in all aspects of scientific inquiry	**NOS3:Subjective** or theory-laden (theoretical, disciplinary commitments , training, and prior knowledge affect the work of scientists)
EF3 (A4): Uses evidence to develop an explanation (e.g. cause for effect, establish relationship based on evidence- use obs. evidence to exp phases of moon)	**U4:**Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations	**NOS4:Creative,** the product of human imagination and inference
EF4 (A5, A6): Connects explanation to scientific knowledge: does evidence support explanation? Evaluate explain in light of alt exp., account for anomalies	**U5:**Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories	**NOS5:Socially and culturally embedded**
EF5 (A7): Communicates and justifies	**U6:**Science advances through legitimate skepticism	**NOS6:**O**bservations** and **inference** distinction
A3: Use of tools and techniques to gather, analyze, and interpret data	**U7:**Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for an investigation, or develop new technologies to improve the collection of data	**NOS7:Scientific theory** and **scientific law** distinction
A8: Use of mathematics in all aspects of inquiry		

Characterization of inquiry instruction. After establishing the presence of inquiry and who initiated the inquiry for all 26 teachers' lessons, we plotted their scores on a modified version of the inquiry continuum (Brown et al., 2006). Once plotted, we looked for groupings that would allow us to characterize instructional practice related to inquiry. Teachers were characterized as either having a robust ability to teach science as inquiry or not having a robust ability to teach science as inquiry. We then selected eight teachers to interview from the group who did not demonstrate a robust ability to teach science as inquiry. These teachers were purposively selected spanning the range from those who had no inquiry in their lessons to those who nearly demonstrated a robust ability to teach science as inquiry. We used a semi-structured interview to corroborate our interpretations and gain a greater understanding of the nature of these teachers' instructional practices (see Appendix B for semi-structured interview).

Table 5. Matrix used to determine who initiated abilities or features of inquiry observed or described in teachers' lessons.

Ability or Feature	4pts	3pts	2pts	1pt
1. Involved in sci-oriented question (EF1, A1)	Student poses a question	Student guided in posing their own question	Student selects among questions, poses new questions	Student engages in question provided by teacher, materials, or other source
2. Design an conduct investigation (A2)	Student designs and conducts investigation	Student guided in designing and conducting an investigation	Student selects from possible investigative designs	Student given an investigative plan to conduct
3. Priority to evidence in resp. to a problem: observe, describe, record, graph (EF2)	Student determines what constitutes evidence and collects it	Student directed to collect certain data	Student given data and asked to analyze	Student given data and told how to analyze
4. Uses evidence to develop an explanation (EF3, A4)	Student formulates explanation after summarizing evidence	Student guided in process of formulating explanations from evidence	Student given possible ways to use evidence to formulate explanation	Student provided with evidence
5. Connects explanation to scientific knowledge: does evidence support explanation? Evaluate explain in light of alt exp., account for anomalies (EF4, A5, A6)	Student determines how evidence supports explanation or independently examines other resources or explanations	Student guided in determining how evidence supports explanation or guided to other resources or alt explanations	Student selects from possible evidence supporting explanation or given resources or possible alt explanations	Student told how evidence supports explanation or told about alternative explanations
6. Communicates and justifies (EF5, A7)	Student forms reasonable and logical argument to communicate explanation	Student guided in development of communication	Student selects from possible ways to communicate explanation	Student given steps for how to communicate explanation
7. Use of tools and techniques to gather, analyze, and interpret data (A3)	Student determines tools and techniques needed to conduct the investigation	Student guided in determining the tools and techniques needed	Students select form tools and techniques needed	Student given tools and techniques needed
8. Use of mathematics in all aspects of inquiry (A8)	Student uses math skills to answer a scientific question	Student guided in using math skills to answer a scientific question	Student given math problems related to a scientific question	Math was used

← Student Initiated — Who initiated aspects of inquiry? — Teacher Initiated →

Characterizing teachers' views of inquiry & NOS. Teachers' views were assessed using a validated, open-response, views of inquiry and NOS survey. We developed the survey over a period of two years drawing on elements of inquiry 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). Because there were slight differences between the survey given to P1 teachers and P2 teachers we used only those items that were identical on the two survey (see Appendix C for survey). We developed our scoring scale based on that of Lederman et al. (2002); however, we modified the original from a three-point scale to a four-point scale (0-3, uninformed understanding-robust understanding). We did this because the four-point scale was more fine grained and would more clearly highlight variance across our population of teachers. Initially, each item was scored independently by two researchers using the four-point scale. Throughout the process the coders consulted with one another to ensure agreement on scores. Next, we analyzed each teacher's responses vertically, across all of the items to help place difficult responses into context using their answers to other items. Finally, we conducted a horizontal analysis, for each item across our participants, to ensure consistency and fine tune the scoring rubric. Interrater 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.

Relation of Views to Classroom Practice. Once we characterized teachers' classroom practice and their views of inquiry and NOS, we looked for relationships between their views and practice. To describe the relationships, we first visually compared the views of inquiry and NOS scores with scores for teaching practice to look for similarities and differences in the data. Next, we correlated scores for the presence of inquiry with views of inquiry scores, views of NOS scores, and combined views inquiry and NOS scores. Additionally, we used information obtained from semi-structured interviews with eight teachers to better understand the relationship between these teachers' views and their teaching practice.

Findings

Characterizing the Nature of Teachers' Instruction

Presence of inquiry & NOS.

Presence of abilities and features. Analyses of multiple data sources revealed that there was a great deal of variation in instructional practice related to inquiry-based teaching across the participants. The variation was particularly evident in the presence or absence of *abilities to do inquiry* and *essential features of inquiry*. *Abilities* and *features* were easily identified because they related to what the learner was doing in the classroom. In some classrooms, all eight of these aspects were observed or described where in other classrooms no *abilities* or *features* were noted at all (see Figure 1).

The teaching of a*bilities* and *features* of inquiry was widespread (i.e. over half of the eight aspects were present) in only a handful of teachers' instruction. In these classrooms, teachers engaged their students in investigations centered on scientifically-oriented questions and had their students collect data. Four of these teachers provided opportunities for their students to use the data they collected as evidence to answer scientifically-oriented questions and share their data with others. An example of this occurred in a lesson described by Darlene.

> *"I start the unit by having students learn how to observe, infer and measure. Then I have them apply these skills to living things such as crickets, worms and snails. First they observe, measure, and make inferences. Then they raise questions that might be answered by doing an experiment. They design their experiment taking care to not harm the animals. The students work in groups of three or four. After their experimental plan is approved, they conduct their experiment, recording data, controlling variables, making qualitative and quantitative observations and completing an adequate number of trials. After completing the experiment, they graph their results and write a conclusion. They share their results with the class. Through this experience, students gain an understanding of the scientific process and practice these skills using their own questions."(Darlene-Application materials)*

In this lesson Darlene described how she engaged her students in many of the *abilities* and *features* of inquiry. Key aspects included students raising questions that could be answered empirically, designing and conducting investigations, giving priority to evidence in responding to a question through organizing the data they collected, using the data they collected to formulate explanations, and sharing their work with their classmates. Additionally, Darlene's students used tools and mathematics to answer scientifically-oriented questions. Similar engagement into the data, including data interpretation and sharing data with others, occurred in three other classrooms. For the remaining two teachers whose lessons exhibited multiple *abilities* and *features*, the focal point of the lesson was on the data collection and not interpretation or the sharing of data. In these two classrooms we observed only one instance of a teacher talking with her students about data. In this classroom the following interaction occurred between Gabriella and her students.

> Gabriella: *What would you say about breathing rate before and after? How would you summarize this? Breathing before and breathing after?*
> S1: *It got faster.*
> Gabriella: *What about our hypothesis? Did we prove or disprove our hypothesis?*
> S2: *Proved it.*
> T: *Right, we proved it! Because after we ran the breathing rate got faster. But the big question is why did we breathe faster after we exercised?*
> Gabriella: *We're tired.*
> T: Okay, we're tired, that's one thing. *What do we need if we are more tired?*
> S3: *We need more air.*
> T: *What is in the air we breathe in?*
> S4: *Oxygen.*
> Gabriella: *Right. Oxygen gives us more energy.*
> Gabriella - ~30:00

This interaction took place at the very end of the class period and was cursory in nature. Moreover, the questions Gabriella asked her students were mostly superficial; she did not appear to push them to make interpretations, rather she made most of the interpretations for them. In an interview conducted with Gabriella she explained that she felt her students were not prepared to interpret the data on their own and needed support in doing this. She shared, "It's very sad. I get

IDK (I don't know). They'll only answer the most literal, lowest level questions…I finally have to ask them leading questions" (Gabriella, interview, 8-6-09 lines 259-260).

In most cases, few aspects of inquiry were evident in teachers' lessons. Those aspects that were common were the more basic *abilities*, such as using tools and mathematics in science class. These *abilities* were often employed as isolated skills, not necessarily connected to a scientific question or any of the other essential features of inquiry. For instance, one teacher asked her students to observe an object under a microscope. Another teacher directed his students to calculate the difference in time between P & S-waves in order to determine when a locale would feel the effects of an earthquake. However, there was no evidence that these teachers engaged their students in anything beyond these basic *abilities* that are similar to process skills. There were also several classrooms where we found no evidence of *abilities* or *features* of inquiry. It is likely that these teachers may engage their students in certain aspects of inquiry from time to time, but we saw no evidence of this in the lessons they chose to highlight.

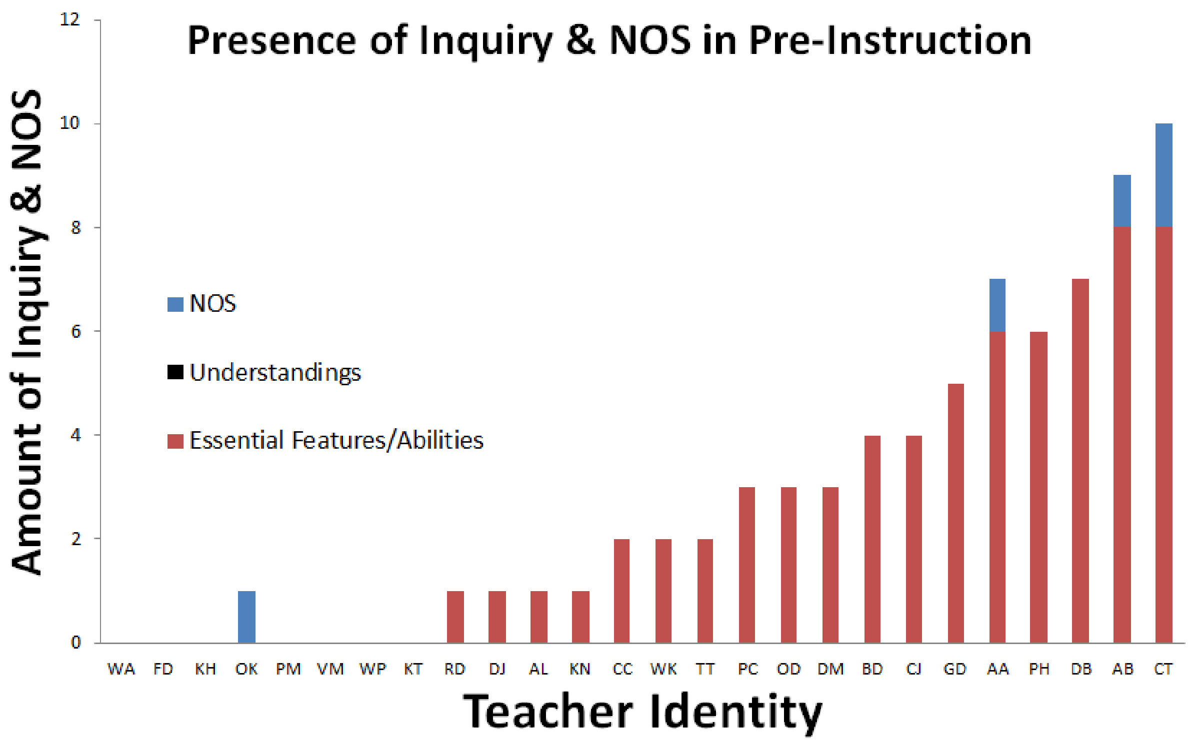


Figure 1. Shows a count of the amount of the essential features/abilities of inquiry, understandings about inquiry, and NOS present in one lesson.

Presence of understandings. Unlike the *abilities* and *features of inquiry* which varied greatly from one classroom to the next, an element of inquiry that was conspicuously absent across all of the participants was instruction related to *understandings about inquiry*. Neither explicit nor implicit instruction related to *understandings about inquiry* was observed or described in any of the lessons (see Figure 1).

Presence of NOS. There was limited evidence of NOS instruction (see Figure 1). We observed NOS instruction in only four of the 26 teachers' classrooms. In each of these classrooms, the teachers included implicit references to NOS, but did not explicitly discuss the topic with their students. For example, Carl, a veteran teacher with 30 years of teaching experience mentioned the tentative NOS when discussing how far geophysics has come since the early days of seismographs. He did not, however, explicitly highlight the fact that scientific knowledge, though reliable and durable, changes over time. Later, in the same lesson he spoke with his students about the subjective NOS. He said,

> *"Is this a lab for true seismologists? Not really, these lines are too thick, the map is too small, and these lines, you have to guess the time between them. Everything you will do will add another piece of error to your answer. There is no wrong answer if you do this correctly. There are some answers that might be a bit better than others…. Part of the confusion is you want it to come out exactly right, but that's not how things are in the real world when you are looking at real stuff…." (Carl, pre-lesson, 5-20-08, ~23:00)*

Here, Carl alluded to the subjective NOS, but did not explicitly help students make this connection. It is very likely that other teachers in our sample also implicitly taught about NOS though we did not see any evidence in the materials teachers submitted. There were several instances where teachers missed out on opportunities to explicitly address aspects of NOS. For example, one teacher was observed teaching a series of lessons on the solar system. Throughout these lessons there were several opportunities to discuss the tentative and subjective NOS in relation to Pluto's change from planet to planetoid. In fact, his students gave him the perfect opening to do so on at least three occasions; however, he did not take the opportunity to do so.

Who initiated the inquiry. Numerical scores for who initiated the inquiry observed or described in teachers lessons ranged from 0-25. The higher the number was, the more student-initiated the inquiry (see Table 6). These scores were determined using Table 5. The eight teachers' lessons that contained no aspects of inquiry were scored a zero, even if the lesson appeared student-centered. Because there was no evidence of inquiry in these lessons, we will not discuss them in this part of the study. Of the remaining teachers' lessons, most (14/18) scored 12 or below. These lessons were considered more teacher-initiated (see Table 5). Only four of lessons were considered more student-initiated.

Table 6. Numerical scores for who initiated inquiry. The higher the score, the more student-initiated the inquiry.

Teacher	DB	CT	PH	AB	AA	CJ	PC	GD	DM	BD	OD	WK	RD	CC	TT	DJ	AL	KN	WA	FD	KH	OK	PM	VM	WP	KT
Score	25	24	17	16	12	8	7	7	7	6	5	4	3	2	2	1	1	1	0	0	0	0	0	0	0	0

The lessons characterized as more student-initiated were all investigations that provided students with at least some autonomy or intellectual ownership over the inquiry. Albert and his students were working with a local biologist to collect data for a national database used by scientists. At the same time, he engaged his students in a classroom investigation looking into explaining presence and absence data of a particular bird species at a local wetland. Along with entering the data into the database, he had his students produce reports to explain patterns they saw in the data. Each student chose the information they wanted to include in the report. Another teacher, Paula, described a series of lessons where her students engaged in two teacher defined questions (i.e. What is the most germy area of the school? and What is the best way to sanitize your hands?). Using these questions, students designed experiments to test their hypotheses, carried out the experiment, and later presented their findings to their classmates and to others. Carl & Darlene both described lessons where their students engaged in full inquires where the question was determined by the students. In both cases, the teacher acted as a guide, supporting the students in their inquiries.

Teacher-initiated lessons included: lectures, hands-on or activity-based lessons (which tended to be group or station work), and investigations. For the most part, these lessons were teacher-driven and highly-structured. Common occurrences in these lessons were teachers explaining concepts to their students or telling their students what they should do or see. Two teachers sent in or described lessons that were lectures. Both used PowerPoint presentations to relay information to their students. The majority of teacher-initiated lessons were hands-on or activity-based exercises with few aspects of inquiry (i.e. *abilities, features,* or *understandings*). In general, these lessons provided little opportunity for student autonomy. Common instructional techniques included teacher demonstrations and group work. For example, Alice taught a lesson where her students built a model of a lung. At the beginning of the class, she passed out the materials her students would need and walked them through the entire process step-by-step from the front of the room. Another teacher, Olive, taught a lesson on heat transfer. After setting students up with the lab she walked from table to table giving advice and talking with students. Several times she was overheard telling her students what they should be doing and seeing. An example of this occurred when she said,

> *"If you can't see the mass of food coloring moving around anymore, then you are done, because that's what you were supposed to see. So the next thing you need to do is draw it and explain it" (Olive pre lesson, 5-10-08, ~35:00).*

Three investigations were categorized as more teacher-initiated. In each of these lessons, the teacher defined the question and led the students step-by-step through the investigation. Paula had her students investigate the question, "What material (plastic or metal) helps heat travel best?" She told her students how they would investigate the question, gave the students the materials they would need, walked the class through collecting data, and helped them answer questions on a worksheet connected to the investigation. Similarly, Gabriella had her students investigate, "What will happen to our breathing after we exercise?" During this investigation Gabriella led her students through a very teacher-directed inquiry. These investigations were highly-structured by the teacher and there was little room for student autonomy.

Characterization of inquiry instruction. Figure 2 plots teachers' scores for the amount of inquiry (*abilities* and *features* only) against who initiated the inquiry. Most of the teachers' lessons plot in the lower left quadrant of the Figure 2, while only a few teachers' lessons plot in the upper right quadrant. The four teachers in the upper right quadrant demonstrated or described an ability to utilize multiple aspects of inquiry in their teaching and engaged their students in less teacher-directed inquiry activities. We thus, characterized these teachers as inquiry teachers because they demonstrated an ability to teach science as inquiry. We did not find as much evidence of inquiry-based instruction in the others' lessons. However, the lack of inquiry in several lessons does not mean that these teachers did not teach science as inquiry. Because the data we used to characterize classroom instruction were limited to application materials, and at most four observations or classroom visits, we conducted semi-structured interviews with eight of the teachers who plotted outside of the upper right quadrant (those who did not demonstrate a high-level of inquiry teaching or student initiated-inquiry) to corroborate our placements and to gain a better understanding of these teachers' instructional practice related to inquiry.

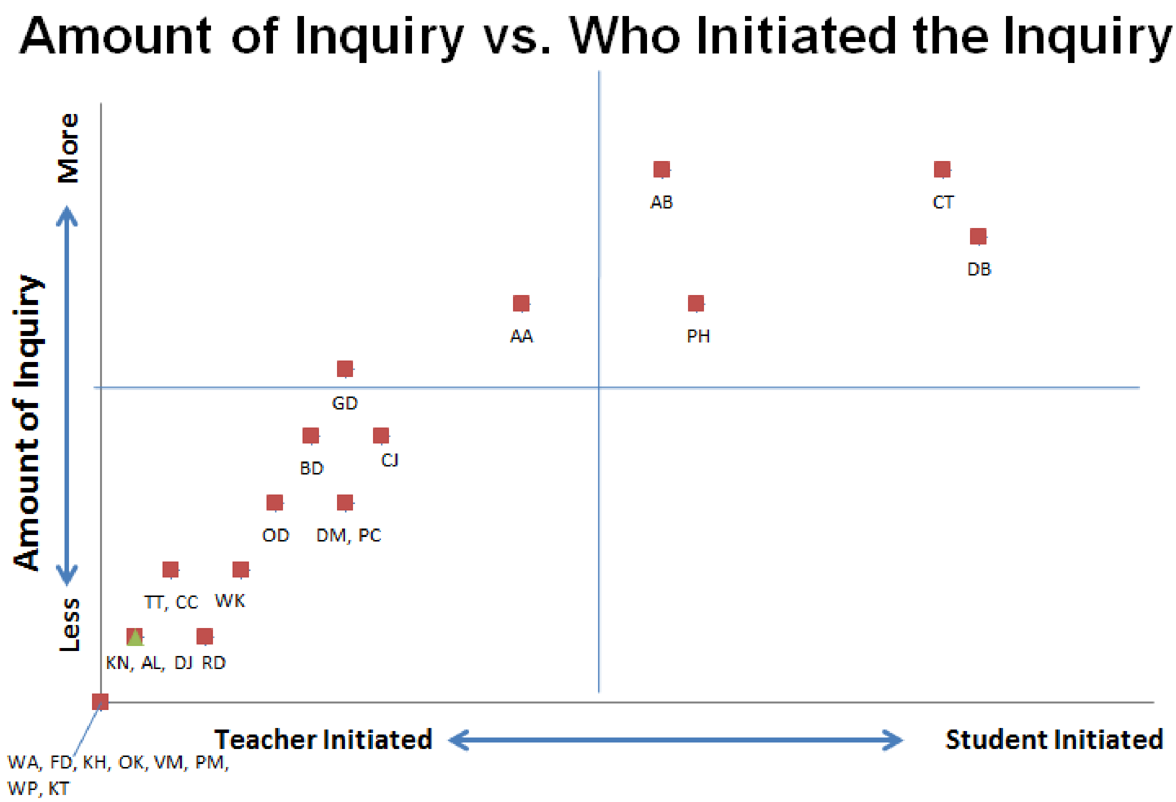


Figure 2. Amount of inquiry versus who initiated the inquiry

Teachers were asked a series of questions about inquiry-based instruction, as practiced in their classrooms (see Appendix B, semi-structured interview questions 6 & 7). Of the eight teachers interviewed, all professed to have used inquiry at least some of the time. However, when asked to identify or describe examples of inquiry-based instruction, most of their examples were not congruent with inquiry defined in reform-based documents. Six of eight teachers identified or described lessons that showed very little evidence of inquiry. The lessons described were normally hands-on, activity-based lessons focused on student discovery or exploration, but incorporated few if any aspects of inquiry. For example, Ron described a chemistry lesson on bonding where his students acted like atoms and bonded with one another. He believed it was inquiry, *"Cuz the kids are getting a chance to play with it and explore. I'm giving them something that we have learned that we have explored through visuals through models through everything else" (Ron, interview, 8-6-09, lines 101-102).*

Based on observational data, all but two of these six teachers plotted in the lower left-hand quadrant of Figure 2. Thus, for the most part, classroom observations and teacher interviews corroborated one another suggesting that inquiry-based instruction was not very common. The two teachers' descriptions that included several aspects of inquiry were an ecosystems unit and a gardening unit. In the ecosystem unit, Brittany's students created a terrarium or aquarium, made observations about the ecosystem, and drew conclusions based on their observations. In the gardening unit, Caelyn's students designed experiments, collected data, and made decisions based on the data they collected. Observation data showed that these two teachers did in fact use some aspects of inquiry in their teaching. Thus, the two data sources appeared to confirm one another.

To further understand teachers' instruction related to inquiry, we framed several interview questions around aspects of the essential features of inquiry we thought might be common in these teachers instruction (see Appendix B, semi-structured interview questions 10, 11, & 12). We analyzed these questions in order to see if teachers were using the features of inquiry in their instruction, even though they might not have been able to articulate what they were. The questions revealed that inquiry was not common in most of the teachers' instruction and when it was, it was teacher-directed. For instance, when asked about questioning, only one of the eight teachers was able to describe an instance where she helped her students develop questions to investigate. In response to the question Caelyn shared,

"A lot of times we try to, as a class, based on our questions, we'll group the questions based on similarity and kind of have a consensus on what we would like to do to further extend what we have already done. So we'll design another investigation to, um… I'll give you an example. During our human body unit we asked questions when we are doing the circulatory system and starting to understand the way in which the heart works, they'll do a number of cardio exercises and record data that way. Different exercises and how it correlates to how many beats the heart makes per minute and they'll take that data and learn to understand resting heart rate and how calories are burned and that kind of stuff." –(Caelyn, interview, 8-6-09, lines 249-270)

Four of the remaining teachers shared that they did not have their students answer scientifically-oriented questions (e.g. "No, I've never done that."- Gabriella). The other three teachers described questions that were not conducive to classroom investigations. For example, one teacher described having her students brainstorm questions they could ask their parents about farming practices they used at home while another discussed having her students think about questions like, "Is there life on other planets and how many stars are there?"

We found that having students work with data was much more common than questioning. Six of the teachers described having their students collect data, graph the data they collected, and explain what it means. These exercises were mostly teacher-directed. Confirming this, one teacher shared, *"I always make them collect data, though as I've found I have to lead them more and more… they really have so little idea of how to organize data that I would just give them a table and help fill them out create a graph from that, so a lot of it was very directed by myself." (Gabriella, interview, 8-6-09, lines 242-247)*

The remaining two teachers, both elementary teachers, also had their students work with data. One had her students work on observing and explaining, without much graphing. The other teacher shared, *"We have [worked with data] but I have limited it to… my first unit in the fall is weather and the atmosphere, or climate and the atmosphere"* (Flo, interview, 8-5-09, lines 160-161). This suggests that working with data did occur in many of the teachers' classrooms.

Having students share and justify findings with others was not very common across the group of teachers that were interviewed. One teacher cited an example of how her students shared findings from a study on their school garden with the rest of the school. The students used these findings to decide what they would do with their garden. Many of the other teachers reported having their students share out with other groups. However, most of their descriptions did not relate to sharing findings, but instead related to students sharing ideas they were discussing in class. Similarly, Flo explained that she had her students share their findings with parents at a science night. Students sung songs and made up raps about science. An example she provided about a song was,

"They took that and talked about the history, and Goddard, the originator and the science behind it, and the Chinese and their gun powder. They created a really cool rap about the history of it and how far we had come, that was really creative." (Flo, interview, 8-5-09, lines 185-187)

This description implies they were not sharing and justifying findings, but were sharing information they learned in science class. Two of the teachers reported not having students share their findings in class, but volunteered that this was something they would like to do.

Based on interviews with eight teachers who did not demonstrate an ability to teach science as inquiry, we found very little evidence of these teachers describing inquiry-based activities or discussing instances where they used particular aspects of inquiry in their classrooms. The most common aspect of inquiry described by teachers in interviews was having their students collect or manipulate data, but few teachers appeared to have their students do more than that. Overall, interview data corroborated observational data suggesting that these teachers did not commonly use many aspects of inquiry in their teaching and when present it tended to be more teacher-initiated. Revisiting Figure 2, we have evidence for two broad categories of teachers, those in the upper-right quadrant who have demonstrated a robust ability to teach science as inquiry and the others who have not. Clearly, there is a continuum of practice between inquiry and non-inquiry teachers, but we do not have the evidence to further divide these teachers.

Summary. Classroom teaching practice related to inquiry and NOS varied across the 26 teachers. Particularly, there was a wide range of *abilities to do* and *essential features of inquiry* observed. In a few of the classrooms, many of these aspects of inquiry were present, where in the majority of the classrooms there was little or no evidence of *abilities* or *features of inquiry*. The most common aspects of inquiry were the basic *abilities*, such as using tools and mathematics in science class. Instruction related to *understandings about inquiry* were not observed or described in any of these teachers' lessons. Moreover, we observed very little evidence of instruction related to NOS across the 26 teachers. The amount of student initiation in aspects of inquiry observed or described was fairly low suggesting that most inquiry was quite structured or teacher-directed. Overall, the evidence we collected including descriptions of teachers' lessons and classroom observations suggest that few of the 26 teachers demonstrated a robust ability to teach science as inquiry. Interviews conducted with eight of the participants confirmed our analysis of classroom observations and descriptions of teachers' lessons.

Characterizing Teachers' Views of Inquiry & NOS

Views of inquiry. Teachers were scored as naïve, emerging, informed, or robust (0, 1, 2, or 3) on items related to inquiry and NOS. Analysis of the pre-views instrument showed that teachers held a range of views of inquiry and NOS from naïve to robust. In general, this group of highly-motivated and well-qualified teachers demonstrated fairly limited understandings of inquiry (Figure 3). The mean score on items related to inquiry was .87/3.0. Five of 26 teachers held naïve views on all three items, while seven others held naïve views on two of the three questions. Only two teachers scored informed or robust on each of the items related to inquiry. When asked on item 6 to articulate what inquiry-based science teaching was, only five teachers gave responses that were considered informed or robust, while the remaining 21 responses were characterized as naïve or emerging. Most teachers (16) gave responses that were considered naïve. This question had the lowest average score of any of the items on the instrument (.65/3.0). A typical naïve response for this question conflated inquiry with hands-on learning. An example of this can be seen in the following response,

> *"I think inquiry-based teaching involves students with a hands-on, related experience that gets them wondering WHY something is the way it is. I think teachers need to have a good sense of the types of questions that the experience will lead to and be there to guide the students' questions, thoughts, etc." (Olga, views survey, 8-9-08, lines 87-89)*

Two teachers' responses to this question were scored as robust. Their views of inquiry conformed to those of inquiry espoused in the *NSES*. For example, in describing inquiry-based teaching, one of these teachers said,

"There's a lot of levels, but certainly the best thing is to let students come up with a problem and have them look into that problem but in a way that has some control, the teacher just can't let them go berserk, they have to have some control. But it really should be a student based problem or maybe a problem that a teacher comes up with, with the kids, that they have interest in and they decide to solve a problem. And then the teacher helps them to come up with the methodology to solve the problem on their own. That's the best case for inquiry. Inquiry can be at a lot of different levels too. Where it's simple, the teacher can totally set it up and the kids

use the thinking through the problem… But certainly, you gather the data, then you manipulate the data, look at the data and come up with some sort of loose hypothesis" (Carl, views survey, 8-9-08, lines 82-91).

In his response, TC demonstrated an understanding of both the balance between student and teacher-directedness and the importance of using data as evidence in developing explanations. These are both important components of inquiry as defined by the *NSES*.

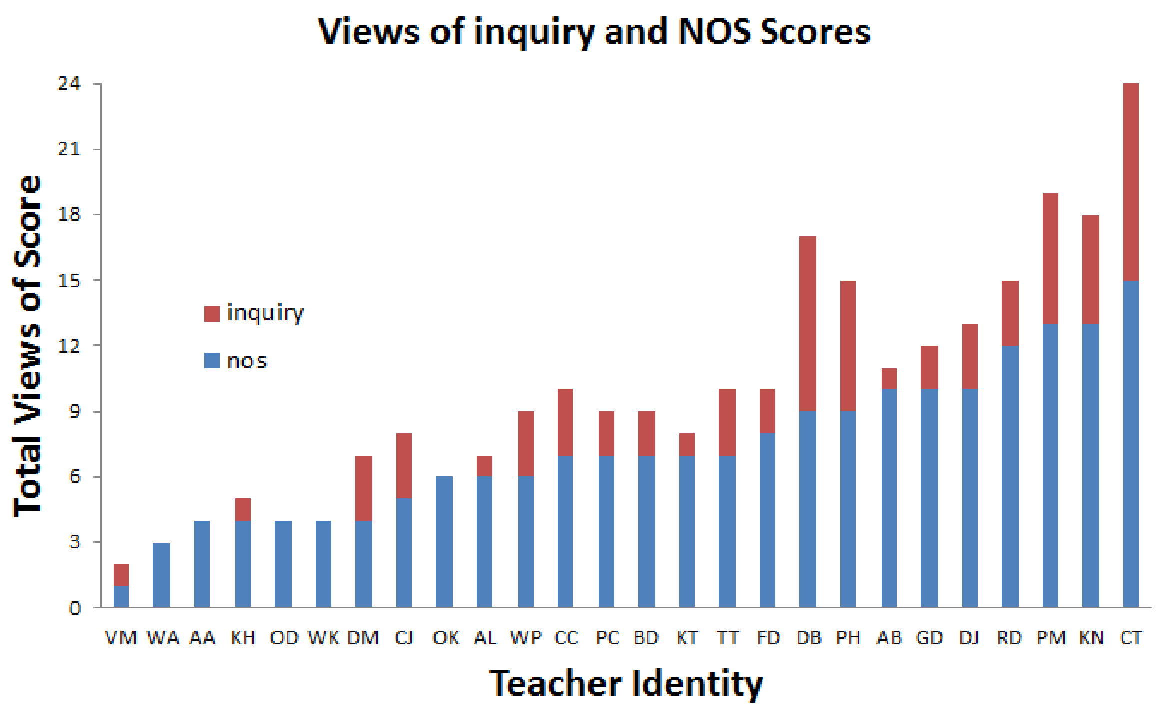


Figure 3. Teachers' views of inquiry and NOS measured by the views survey.

Most of the teachers (21/26) held naïve or emerging views on item 7 related to the scientific method. The average score on this question was 0.96/3.0, or slightly below emerging. These teachers viewed the scientific method as a rigid set of steps that all scientists follow or as a series of steps that scientists follow, but not always in the same order (i.e. the order of the steps might change, but they will still be present). Only five of the participants believed the scientific method varied depending on the question being asked or the goals of the project. Several of these teachers mentioned that the scientific method we teach in school is a model or a simplification for how some science is done.

Item 8 focused on the teachers' ability to do scientific inquiry. It asked them to describe how they might investigate how organisms or climate changed throughout the geologic past. The average score on this question was 1.0/3.0, or emerging. Eighteen of the teachers scored naïve or emerging on this question. Many of the teachers in these two groups were able to talk about what kinds of data might be collected, but they had trouble explaining what one would do with the data once it was collected.

Data from interview questions related to teachers' views of inquiry corroborated teachers' written responses. Few of the teachers verbally articulated informed or robust views of inquiry. Those teachers we interviewed who held more robust views on inquiry on the survey were better able to verbalize their views than those who held more naïve conceptions of inquiry. For example, even though Kendra struggled in describing what inquiry-based instruction was, she did have more robust views on other aspects of inquiry. For example, in discussing the scientific method she said,

> *"Sure, I mean, the pieces [of the scientific method] I think are absolutely valid, and I think the skills, there are certain skills that go with those pieces that I think are critically important to being a scientist, and thinking like a scientist, and acting like a scientist, and exploring your world, that I think the step by step process that we made them follow um is not very valid…it doesn't seem to me that this is the way it goes" (Kendra, interview, 8-5-09, lines 45-48).*

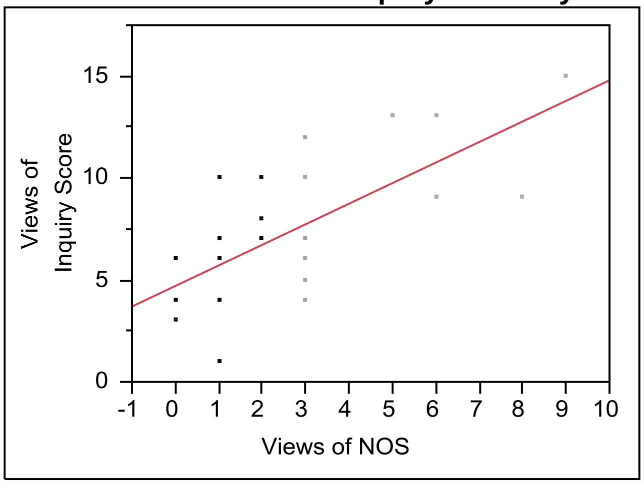
Whereas teachers who held more naïve views of inquiry felt the scientific method was fairly rigid. Amanda shared,

> *"We talk about how you use the scientific method everywhere even to cross the street. We talk about what the scientific method is we kind of usually, just a review, because they generally have had it. We talk about why it is important to have and something else that I learned through them is that the scientific method is kind of written in different ways but it really is essentially the same thing. Some people have 7 steps, and some have 5 and were really just kind of helping the kids it's just the idea that you want to get across" (Amanda, interview, 8-6-09, lines 348-353).*

Views of NOS. Views of NOS also varied across the sample; however, the overall score on these items was higher than the average inquiry score (1.4/3 as opposed to 0.87/3). Although no teacher scored naïve on each of the items related to NOS, four teachers scored either naïve or emerging on all five items, whereas, four others scored informed or robust on the on all five items. The lowest NOS scores came on items 1 and 3. The average score on item 1 was 0.92/3.0, slightly under emerging. On this question, only two teachers recognized that the methods used in science (e.g. observational, experimental, theoretical) depended on the question being asked by the scientist. The remaining teachers either responded that there were a variety of ways to do science, but did not elaborate on this, or articulated that all science was experimental. The average score on item 3 was 1.1/3.0, slightly over emerging. Here, most teachers understood that different people had different interpretations based on their backgrounds, but only four teachers connected one's interpretations to both socio-cultural factors and creativity. Teachers had the highest average score on item 5 (2.3/3.0) which dealt with differentiating between observations and inferences. Most teachers (22/26) held informed or robust views. In general, these teachers were able to describe the difference between the two and provide an appropriate example of each. The few teachers whose views were less adequate had difficulties describing the difference between the two concepts (e.g. "*An observation is witnessed, cause and effect. An inference is what a scientist cannot see, parts of an atom" Vanessa, views survey, 8-9-08, lines 97-98*).

Results from a simple linear regression model indicated there was a positive linear relationship between teachers' views of inquiry and their views of NOS. This relationship was statistically significant ($p<0.0001$). An additional unit increase of NOS score was associated with a 1.0 unit increase (SE=0.2034) in inquiry score. Fifty percent of the variation in views of inquiry score could be explained by the views NOS score.

Bivariate Fit of Views of Inquiry Score By Views of NOS Score



Parameter Estimates

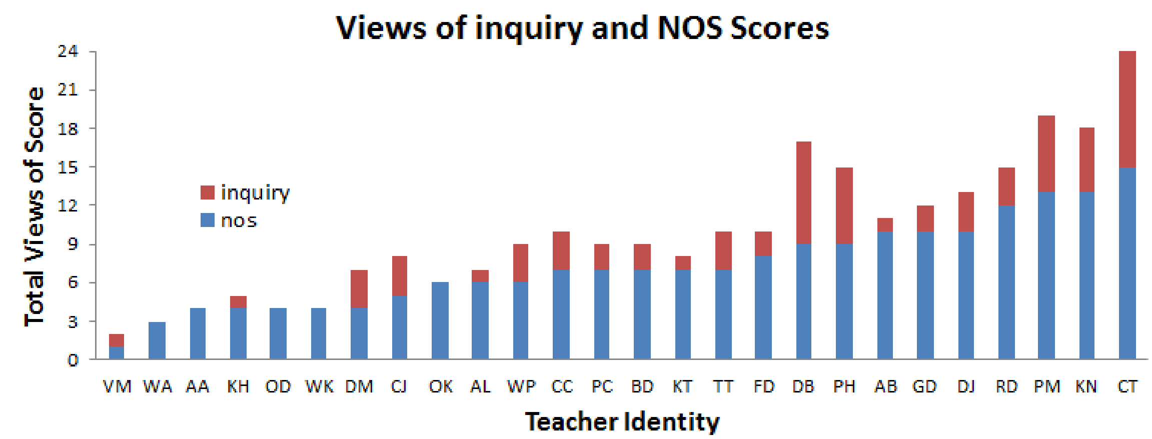
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.7076843	0.720231	6.54	<0.0001*
Views of NOS Score	1.0088266	0.2034	4.96	<0.0001*

Figure 4. Correlation between views of inquiry and NOS scores

Summary. Teachers views of inquiry and NOS varied from uniformed to robust on each item. The average inquiry score was 0.87/3.0 suggesting teachers held fairly limited views of inquiry. The lowest average score came on an item asking teachers to describe inquiry-based instruction. For NOS, the average score was 1.4/3.0, slightly higher than the average inquiry score. Still, teachers held fairly limited views of NOS. There was a positive linear relationship between teachers' views of inquiry and NOS, suggesting an association between teachers' views on inquiry and NOS.

Relation of Views to Classroom Practice

Analysis of the data indicates that teachers who employed multiple aspects of inquiry in their instruction generally held more informed views of inquiry and NOS while teachers who employed fewer aspects of inquiry held less informed views of inquiry and NOS. This pattern can be observed in Figure 5. Teachers who plotted on the right side of the inquiry and NOS classroom practice chart (e.g. CT, AB, DB, & PH) also tended to plot on the right side of the summed views of inquiry and NOS chart. Whereas teachers in the middle or on the left side of the inquiry and NOS classroom practice chart normally plotted in a similar place on the views of inquiry and NOS chart. Although there appears to be a fairly good correspondence between a teacher's views of inquiry and NOS and his or her teaching practice, there were some exceptions. Two notable exceptions to this pattern were AA and MPD. AA held fairly limited views of inquiry and NOS, but employed multiple aspects of inquiry in the lessons we observed, and MPD held fairly robust views on inquiry and NOS but we found little evidence of inquiry in our analysis of classroom video and descriptions of her lessons.



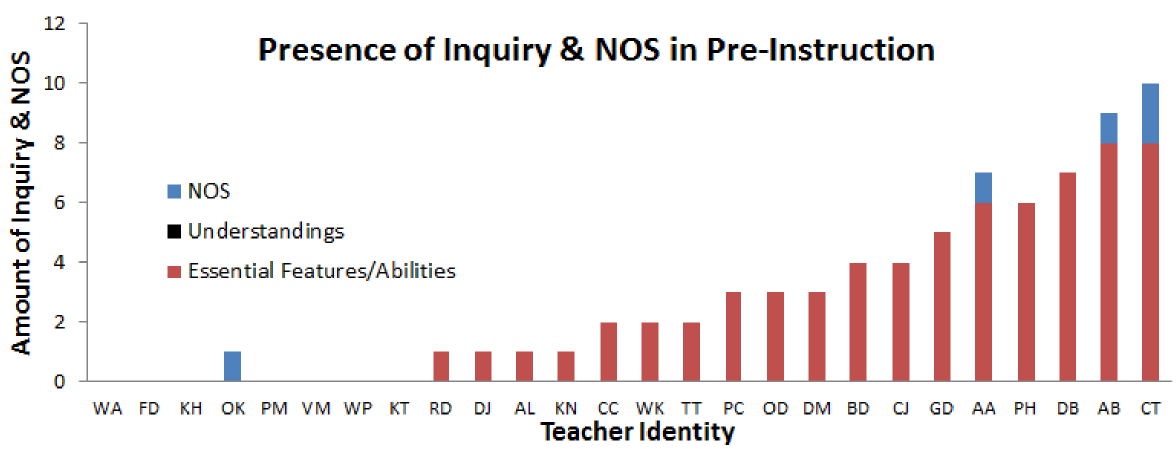


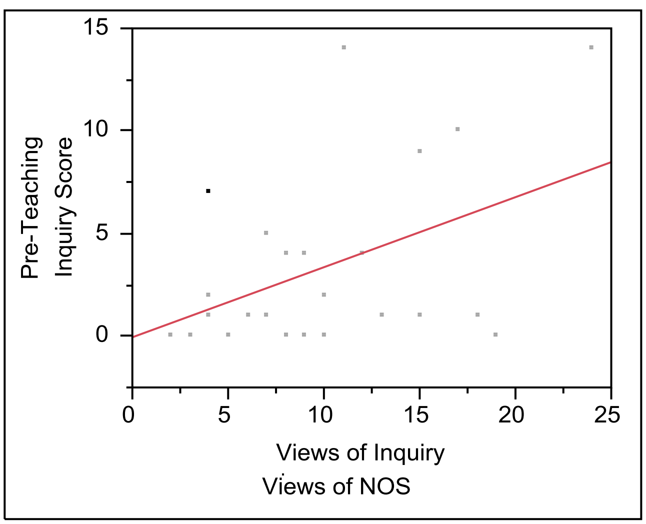
Figure 5. Displays a visual comparison between the presence of inquiry and NOS in teachers pre-program instruction and their views on inquiry and NOS.

Results from simple linear regression models indicated there was a positive linear relationship between teachers' inquiry teaching score and their views of inquiry (Figure 6). There was also a positive linear relationship between teachers' inquiry teaching score and their views of inquiry and views of NOS summed score (Figure 7). These relationships were statistically significant ($p<0.0138$ and $p<0.0226$). An additional unit increase in views of inquiry score was associated with a 0.82 unit increase (SE=0.0385) in inquiry teaching score, while a unit increase in views of inquiry and NOS score was associated with a 0.34 unit increase (SE=0.1401) in inquiry teaching score. About 20 percent of the variation in inquiry teaching score could be explained by the views of inquiry and views of inquiry and views of NOS score. There was not a linear relationship between teachers' inquiry teaching score and their views of NOS (Figure 8). When the most anomalous scores were dropped from the sample (AA and PM), two teachers who used more inquiry than their views scores would suggest, the relationships between views and teaching practice become much stronger and all three relationships were significant.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	99.57828	99.5783	7.0642
Error	24	338.30633	14.0961	**Prob > F**
C. Total	25	437.88462		0.0138*

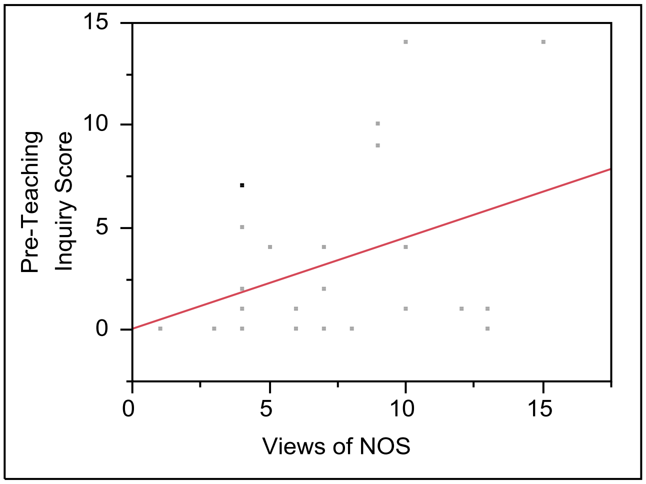
Figure 6. Simple linear regression comparing teachers' inquiry teaching score (*abilities* and *features* of inquiry) with their views of inquiry score from the views survey.



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	86.83934	86.8393	5.9370
Error	24	351.04528	14.6269	**Prob > F**
C. Total	25	437.88462		0.0226*

Figure 7. Simple linear regression comparing teachers' inquiry teaching score (*abilities* and *features of inquiry*) with their combined views of inquiry and NOS score from the views survey.



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	59.27906	59.2791	3.7577
Error	24	378.60555	15.7752	**Prob > F**
C. Total	25	437.88462		0.0644

Figure 8. Simple linear regression comparing teachers' inquiry teaching score (*abilities* and *features* of inquiry) with their views of NOS score from the views survey.

Interestingly, when asked if the lessons they described and we observed represented inquiry-based instruction, all of the eight teachers we interviewed identified at least one of the lessons as 'inquiry-based', even though our analysis of these lessons showed little evidence of inquiry. In describing why the lessons were inquiry, common themes that emerged were: the role of questioning, with no mention of a scientifically-oriented question (5 times); being student-centered (5 times); and being hands-on (5 times). There was little mention of aspects of inquiry as defined in reform-based documents. Only four teachers used words that may have indicated inquiry. The following comments were each made by one teacher: students making observations and drawing conclusions, students experimenting and classifying, students hypothesizing, and students guessing based on their observations. Furthermore, five of the eight teachers verified that the lessons we observed, that had little evidence of inquiry, were fairly representative of the way they taught. Thus, many of these teachers believed they were frequently teaching science as inquiry; when in reality, they were not.

Summary. There appeared to be an association between teachers' views of inquiry and NOS and their teaching practice related to inquiry. Teachers with more robust views appeared more likely to use inquiry-based instruction as a teaching strategy. There was a statistically significant relationship between teachers' inquiry-based teaching practice and their views of inquiry and their views of inquiry and NOS, but not between their teaching practice and their views of NOS. Interview data suggested that many teachers who were not teaching science as inquiry believed that they were since they involved their students in questioning, used student-centered approaches, and used hands-on teaching practices.

Discussion

The motivation for this study was to describe and analyze the teaching practice and views of a group of highly-motivated and well-qualified 5^{th}-9^{th} grade teachers. Specifically, our aim was to provide empirical evidence for the presence or absence of inquiry and/or NOS instruction, assess these teachers' views of inquiry and NOS, and look for relationships between their views and practice. Inquiry-based instruction is a fundamental science teaching strategy. Throughout the past, reform movements have emphasized the importance of inquiry in helping students learn (e.g. Dewey, 1910; Schwab, 1966; AAAS, 1989; NRC, 1996). Moreover, inquiry-based instruction provides a context for teaching understandings about inquiry and NOS (Carey et al. 1993; Schwartz et al., 2004), which are important components to scientific literacy (AAAS, 1989; Hodson, 1992; NRC 1996).

Nature of Teachers' Instruction

Inquiry. In the introduction to this paper we pointed to the lack of recent empirical studies describing teachers' instructional practice related to inquiry. In order to address this issue, we analyzed the teaching practice of 26, 5^{th}-9^{th} grade teachers. Using classroom observations and descriptions of lessons, we found that there was a wide range of instructional practice related to the *abilities to do* and *essential features of inquiry*. This variation was not surprising given the different backgrounds of the teachers involved in the program. Of the four teachers who demonstrated an ability to teach science as inquiry, we found no single factor in their background that could account for this (see Appendix A). For example, one might expect a teacher who had science research experience to be able to teach science as inquiry, though one of the four teachers who demonstrated an ability to teach in this way had no research experience. Moreover, several teachers with research experience did not demonstrate an ability to teach science as inquiry. What the four inquiry-based teachers did have in common was abundant experience in teaching and learning science. Each of these teachers taught for a minimum of ten years, took at least seven, if not many more university science courses, and either had multiple science professional development and/or research experiences. Likely, what separated these teachers from the others was their ability to draw on their rich experiences as science teachers and learners to enact inquiry-based instruction in their classrooms. This underscores the important influence of one's experience and practical knowledge on their teaching practice (van Driel et al., 2001).

We were surprised by the lack of inquiry in the lessons of the remaining highly-motivated, well-qualified teachers. In analyzing their lessons and interviews we found little evidence of *abilities* and *features of inquiry* beyond the use of fairly simple process skills and at times the collection of data. Inquiry is an important science teaching strategy that many teachers strive to use. Given that the focus of the professional development program would be on inquiry, and teachers had the freedom to select the lessons they described and we observed, we expected these teachers would select some of their better lessons giving us a best case scenario of their teaching practice. Consequently, we believe if anything, our analyses likely exaggerate the amount of inquiry and student-initiated inquiry actually carried out in these teachers' classrooms.

Because the 26 participants were selected from an applicant pool of highly-motivated teachers interested in improving their teaching on their own time; we can assume that inquiry-based instruction is probably even less common in 5^{th}-9^{th} grade teachers' instruction as a whole. In other words, things may be even more dismal than they appear in this study.

Instruction related to *understandings about inquiry*, either implicit or explicit, was not observed or described in any classroom. This was troubling given that *understandings about inquiry* are a major component of inquiry-based instruction (NRC, 2000). We argue that teaching *understandings about inquiry* are similar to teaching about NOS in that they should be taught explicitly (Lederman, 2004). Implicit instruction assumes that students will learn about inquiry in the process of an investigation. This, however, may not always be true.

NOS. Generally speaking, the presence of instruction related to NOS was not common in the lessons we analyzed. There were only a few instances of implicit instruction and no explicit instruction. Implicit instruction is not enough to support learners in understanding NOS (Lederman, 2004). The literature on NOS expresses the importance of explicit instruction to support learners in developing conceptions of NOS consistent with those advocated by science education reform documents (Abd-El-Khalick & Lederman, 2000). The paucity of instruction related to NOS and the complete lack of evidence of explicit instruction about NOS is an important finding. NOS is a well researched topic in science education. Multiple journal articles are published each year, and entire strands are devoted to the topic at annual meetings; however, the import placed on NOS by researchers does not appear to have reached even some of the best teachers.

Views of Inquiry & NOS

Analysis of the views of inquiry and NOS survey revealed a range of understandings across the 26 teachers. However, most of these teachers held fairly limited views and misconceptions on inquiry and NOS. Interviews conducted with eight of the teachers confirmed this. Teachers with inadequate views on inquiry and NOS will not likely be successful in enacting inquiry-based instruction in their classrooms or in teaching about inquiry and NOS. The apparent association between views of inquiry and views of NOS scores suggests that more informed views of one may result in more informed views of the other. This highlights the importance of supporting teachers in learning about inquiry and NOS so that their views align with reform-based documents. Science education reform documents that define teaching strategies like inquiry, and concepts like inquiry and NOS, are now ten to twenty years old or older (e.g. AAAS, 1989; NRC, 1996). It is disconcerting to learn that teachers are still unfamiliar or struggling with these ideas. The fact that many of these well-qualified teachers mistakenly equated inquiry-based science teaching with other teaching methods, like hands-on instruction and discovery learning, suggests that there is likely even more confusion in the population as a whole.

Relation of Views to Classroom Practice

Analysis of data indicated an association between teachers' views and their classroom practice. That is, teachers with more robust views were more likely to teach science as inquiry where teachers who held more limited views were less likely to teach science in this way.

Significant relationships existed between teachers' views of inquiry and inquiry teaching practice and teachers' views of inquiry and NOS and inquiry teaching practice. Given that teacher knowledge affects classroom practice (Cochran-Smith & Lytle, 1999), and many teachers in this study held limited views of inquiry, it is unlikely that many of these teachers taught science as inquiry or taught about inquiry and NOS. Further evidence for the lack of inquiry-based instruction and the relationship between teachers' views and their practice came from analysis of interviews conducted with eight teachers selected from the group who showed little evidence of teaching science as inquiry. All of the eight interviewed believed they were teaching science as inquiry at least some of the time. When asked to describe features of inquiry in their instruction their examples equated inquiry with questioning, student-centered teaching approaches, and hands-on teaching. These ideas relate to many of the misconceptions and myths educators have about inquiry (Haury, 1993; NRC, 2000).

Teaching science as inquiry and teaching explicitly about the NOS is not easy. Previous research has identified a number of external and internal factors that may prevent teachers from incorporating reform-based teaching strategies like inquiry and explicit teaching of NOS into their teaching. Some of the factors external to the teacher include: lack of time (Abell & McDonald, 2004; Newman et al., 2004), concerns over financial constraints (Abell & Roth, 1992; Finson et al., 1996; Ginn & Watters, 1999; Morey, 1990), lack of administrative or community support (Lee & Houseal, 2003), and classroom management issues (Roehrig & Luft, 2004). Whereas common factors internal to the teacher include: a lack of content or pedagogical knowledge (Carlsen, 1993; Gess-Newsome, 1999; Hashweh, 1987, Shulman, 1986) and beliefs that are inconsistent with teaching in this way (Pajares, 1992; Roehrig & Luft, 2004). In choosing a population of highly-motivated and well-qualified teachers, with administrative support, we attempted to minimize many of the factors that commonly prevent teachers from using reform-based teaching approaches, like inquiry. Thus, it is safe to assume that we would see more evidence of inquiry-based instruction and instruction about NOS in these teachers' lessons than in the population at large. However, we found very little evidence of this type of instruction suggesting that inquiry-based instruction and teaching about inquiry and NOS is uncommon in most classrooms. The limited views of inquiry and NOS expressed by many of the 26 teachers involved in this study is a likely reason for why many of these teachers were not using reform-based teaching approaches. Furthermore, the fact that most teachers interviewed believed they taught science as inquiry, but were unable to describe an actual lesson they taught that conformed to inquiry outlined in reform-based documents, implies a disconnect between teachers' views on inquiry and their actual practice.

Conclusions and Implications

Although reform-documents highlight the importance of inquiry and NOS, this study indicates that even some of the best teachers struggle to articulate what inquiry and NOS are and in teaching science in accordance with these ideas. Furthermore, many of these well-qualified teachers believed they were teaching science as inquiry when they actually were not. The findings from this study point to the critical need for professional development to support teachers in learning about what inquiry and NOS are, and in enacting reform-based instruction in their classrooms. Teaching science as inquiry and about NOS are complex and sophisticated instructional approaches that demand significant professional development (Crawford, 2000, 2007). We suggest that teacher educators work with preservice and inservice teachers in articulating their views of inquiry and NOS and support them in comparing how their views relate to conceptions of inquiry and NOS in reform documents. Moreover, teacher educators should provide opportunities for preservice and inservice teachers to engage in their own inquiries where they are assisted in explicitly learning about aspects of inquiry and NOS that their students should know. Teacher educators should also provide their students with opportunities to practice teaching science as inquiry and about inquiry and NOS. If we expect teachers to use new instructional techniques, they will need to have opportunities to teach in this way (Loucks-Horsley Love, Stiles, Mundry, & Hewson, 2003). Teachers should also be supported in learning how to reflect on their own teaching practice so they can begin to see how their instruction relates to reform-based teaching. Finally, the fact that many teachers believed they were teaching science as inquiry, but in reality were not, suggests that teacher self-report alone may not provide an accurate picture of what teachers are actually doing in their classrooms related to inquiry. This highlights the importance of using alternative data sources like classroom observation and interviews to characterize teachers' instruction related to inquiry and NOS (Capps, Crawford, & Constas, *in press*).

Appendix A

Table 3. Background information for Fossil Finders teachers; pilot group 1 teachers are in white while pilot group 2 are shaded.

Teacher	Grade level	Education	Teaching	College Sci Courses	Research Exp	Sci. PD Exp	Gender
AW	5/6	BA-Psychology	11	4	No	1	F
JD	5/6	BA-Int. Relations	4	2	No	2	M
MV	5/6	BA-Psychology	5	1	No	9	F
KW	5/6	BA-Elem Ed	4	1	No	3	F
MD	7/8	BS-Biology	9	16	Yes	1	F
DO	7/8	BS-Biology	4	23	No	3	F
LA	7/8	BS-Biology	5	13	Yes	3	F
TC	8/9	BS-Geology	30	31	Yes	14	M
TT	9	BS-Biology	13	26	No	3	F
PW	8/9	BS-Earth Sci	5	17	No	1	M
AA	5th-8th	BA-Education	5	6	No	5	F
BA	5th	BS-Electrical Eng.	14	15	Yes	2	M
DB	6th	BA-Elementary Ed	4	3	No	0	F
CC	8th	BA-Elementary Ed	9	10	Yes	1	M
JC	5th	BS-Elementary Ed	2	7	No	2	F
BD	7th	BA-Fine Arts	10	7	Yes	4	F
DF	6th	BS-Physical Therp	19	4	No	8	F
DG	8th	BA-Anthropology	5	16	No	3	F
CHP	6th-8th	BS-Elementary Ed	22	9	No	3	F
NK	7th	BS-Biology	5	16	Yes	0	F
HK	5th	BA-Education	20	2	No	3	F
TK	7th	BS-Chemistry	3	14	No	1	F
KO	5th	BS-Education	23	1	No	1	F
MPD	7th	BA-Bio/Chem	22	32	Yes	4	F
HP	7th	BS-Elementary Ed	32	7	No	10	F
DR	8th	BS-Science Ed	2	21	No	1	M
AVG			**11.0**	**11.7**		**3.4**	

Appendix B

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?

Appendix C

Views Survey

1. Does science always involve doing experiments? Please explain your answer.
2. What is a scientific theory? 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.
3. 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.
    - How are these different hypotheses possible if both groups of scientists have access to and use the same data to derive their hypotheses?
    - Is it possible for two different scientists to perform the same scientific procedures and reach different conclusions? Please explain your answer.
4. 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.
5. Are *observations* the same as or different from *inferences*? Please explain your answer using examples.
6. Current reform documents in science education call for teaching "science as inquiry". What does this mean? How would inquiry-based teaching look in your science classroom?
7. What is the scientific method? Do all scientists use the scientific method? Please explain your answer.
8. Explain the process a paleontologist might use to research how climate has changed throughout the geological past in NY.

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