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Inquiry-Based Instruction and Teaching About Nature of Science: Are They 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 aimed to provide evidence-based documentation of the state-of-use of inquiry-based instruction and explicit instruction about nature of science (NOS). We examined the teaching practice and views of inquiry and NOS of 26, well-qualified and highly motivated 5th–9th-grade teachers from across the country in order to establish the extent to which their views and practice aligned with ideas in reform-based documents. We used a mixed-methods approach analyzing lesson descriptions, classroom observations, videotape data, questionnaires, and interviews to assess teaching practice and views of inquiry and NOS of these teachers. We also determined the relationships between teachers' views and their teaching practice. Findings indicated the majority of these teachers held limited views of inquiry-based instruction and NOS. In general, these views were reflected in their teaching practice. Elements of inquiry including abilities, understandings, and essential features were observed or described in less than half the classrooms. Most commonly, teachers focused on basic abilities to do inquiry instead of the essential features or important understandings about inquiry. When aspects of inquiry were present, they were generally teacher-initiated. There was also little evidence of aspects of NOS in teachers' instruction. This study provides empirical evidence for

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the claim that even some of the best teachers currently struggle to enact reformed-based teaching. Further, it highlights the critical need for an agreement upon definition of inquiry-based instruction and the need to develop appropriate and feasible assessments that specifically target inquiry to track changes in teachers' views and practice. Important implications include the heightened need for rigorous and continuous professional development to support teachers in learning about inquiry and NOS and how to enact reform-based instruction in classrooms.

Keywords Inquiry · Nature of science · Views · Practice

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 [AAAS] 1989, 1993; National Research Council [NRC] 1996, 2000). 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). A recent synthesis of the literature by Minner et al. (2010) indicated a clear positive trend between inquiry-based instruction and conceptual understanding for students. 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, many teachers have limited experience with scientific inquiry and hold naïve conceptions of the process by which scientific knowledge is generated (Anderson 2007). Lack of knowledge and experience with inquiry is thought to act as a barrier for teaching science in this way (Blanchard et al. 2009). This lack of knowledge and experience likely puts serious limitations on teachers' ability to plan and implement lessons that will help their students develop an image of science that goes beyond the familiar body of knowledge. In order for teachers to enact reform-based teaching practices in their classrooms, like inquiry and explicit instruction about nature of science (NOS), it seems reasonable that they will need to develop: (1) adequate understandings about inquiry and NOS, (2) their own abilities to do inquiry, (3) the pedagogical skills necessary to teach science as inquiry and about NOS, and (4) the intention to teach in this way.

Although science educators report that teachers do not typically use inquiry-based instruction in their classrooms, there is little empirical evidence in the literature to support this claim. In reviewing the literature on inquiry-based instruction, we determined that many recent articles cite a few past reports as evidence that teachers are not teaching science as inquiry. The reports referenced in these articles include a series of case studies from the 1970s (Stake and Easley 1978), classroom observations of science and mathematics teachers in the Looking Inside the Classroom study (Weiss et al. 2003), and the TIMSS video study of Eighth-Grade Science teaching (Roth et al. 2006). Inquiry-based instruction was not the focal point of any of these studies. Articles also referenced teacher self-report data from large-scale surveys (e.g., US Department of Education 1999) to document the lack of inquiry-based instruction. Finally, some articles gave anecdotal accounts (e.g., Lord and Orkwiszewski 2006; Radford 1998; Wells 1995) or cited the anecdotal accounts of others (e.g., Windschitl 2002) when commenting on the lack of inquiry-based teaching. Thus, in reality, there is a lack of empirical evidence documenting the actual state of affairs related to inquiry-based science instruction in classrooms. Most of the data come from generalized studies, teacher self-reports, and anecdotal evidence. The aim of the present study was to investigate the views and actual practices related to inquiry and NOS of a group of highly motivated and well-qualified teachers from classrooms across the United States. Specifically we asked:

1. What was the nature of teachers' instruction?
2. What were these teachers' views of inquiry and NOS?
3. What was the relationship between teachers' views of inquiry and NOS and their teaching practice?

Theoretical Framework

Teaching Science as Inquiry and Teaching about NOS

There are many faces of inquiry, much like the many faces of constructivism articulated by Phillips (1995). In this study, we based our view of classroom inquiry on the U.S. science education reform documents that describe three different faces or elements of inquiry. The first two elements are educational outcomes, and the third is a teaching strategy (NRC 1996, 2000). First, inquiry can be thought of as a content area. In this sense, learners begin 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). These 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. A second element of classroom inquiry is a student's ability to do scientific inquiry (NRC 1996). Abilities to do inquiry include asking and identifying questions, planning and designing experiments, collecting data using data, and connecting data as evidence with explanations. Third, classroom inquiry can be viewed as a kind of pedagogy, or a teacher's ability to employ inquiry-based instruction in the classroom in order to address key science principles and concepts (NRC 2000, 2012). Inquiry as a science teaching strategy includes the five essential features of inquiry and their variations (see Table 1 for a list of the understandings, abilities, and essential features of inquiry and Table 2 for variations on inquiry). 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

Table 1 List of understandings about inquiry, abilities to do inquiry, essential features of inquiry (NRC 1996, 2000), and NOS (Lederman et al. 2002)

Understandings about inquiry U = Understandings about inquiry	Doing inquiry D = Doing inquiry Derived from the important abilities (A) and essential features (EF) of inquiry	Nature of science NOS = Nature of science
U1: Different kinds of questions suggest different kinds of scientific investigations	*D1* (EF1/A1): Involved in sci-oriented problem	*NOS1: Tentative* or subject to change
U2: Current scientific knowledge and understanding guide scientific investigations	*D2* (A2): Design an conduct investigation	*NOS2: Empirically based* (based on and/or derived from observations of the natural world)
U3: Mathematics is important in all aspects of scientific inquiry	*D3* (E2): Priority to evidence in resp. to a problem: observe, describe, record, graph	*NOS3: Subjective* or theory-laden (theoretical, disciplinary commitments, training, and prior knowledge affect the work of scientists)
U4: Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations	*D4* (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)	*NOS4: Creative*, the product of human imagination and inference
U5: Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories	*D5* (EF4/A5, A6): Connects explanation to scientific knowledge: does evidence support explanation? Evaluate explain in light of alt exp., account for anomalies	*NOS5: Socially and culturally embedded*
U6: Science advances through legitimate skepticism	*D6* (EF5/A7): Communicates and justifies	NOS6: Scientific knowledge is created from *observations* and *inferences*
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	*D7* (A3): Use of tools and techniques to gather, analyze, and interpret data	*NOS7: Scientific theory* and *scientific law* distinction
	D8 (A8): Use of mathematics in all aspects of inquiry	

This list was used to develop codes (described in Methods and Data Sources) to determine the presence (1) or absence (0) of aspects of doing inquiry, understandings about inquiry, and aspects of NOS observed or described in teachers' lessons

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, helps students develop deeper understandings of science, and most importantly, can lead to critical thinking skills. Moreover, inquiry-based instruction provides a fruitful context to address understandings about inquiry and NOS (Carey and Smith 1993; Schwartz et al. 2004).

Instruction related to NOS has been an important goal of science education for nearly a century (Lederman 2007). 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 agreement of all aspects of NOS (Duschl 1990), there is a general consensus on aspects of NOS thought accessible in K-12 classrooms (e.g., Lederman et al. 2002; McComas et al. 1998). See Table 1 for a list of these aspects. The past studies have shown that many teachers and preservice teachers do not hold adequate views of NOS (e.g., Abd-El-Khalick and BouJaoude 1997; Ackerson and Donnelly 2008; Carey and Stauss 1970). Adequate views of NOS are those that align with reform documents (e.g., AAAS 1993; NRC 1996, 2012). It seems reasonable to assume that inadequate views of NOS held by teachers may prevent teaching about NOS. Moreover, it has been noted that even if teachers hold adequate views of NOS, they may not support their students in learning about NOS (Lederman 2007). In order to promote student learning about NOS, it has been suggested that teachers explicitly discuss aspects of NOS as they come up in classroom instruction (Akindehin 1988; Schwartz et al. 2004; Lederman 2007).

Scientific inquiry and NOS are related, yet different constructs in regard to the goals of contemporary science teaching. Teaching children to do scientific inquiry involves teachers engaging their students in the practices of science. These practices include the various activities and processes carried out by scientists to answer questions and develop explanations and models using logic and critical thinking (NRC 2012). As they engage in scientific practices, both students and scientists use observations and inferences to develop conclusions and evidence-based explanations (AAAS 1989). Understanding the importance of observations and inferences, as well as the tentativeness, subjectivity, and cultural aspects of science associated with the development of scientific knowledge are characteristics of NOS. These aspects are also associated with understandings *about* scientific inquiry. Engaging students in authentic scientific experiences is argued to provide a context for reflection on NOS, but experience alone is not sufficient to change students' and teachers' views of NOS (Schwartz et al. 2004). For an extensive treatment of the overlapping, yet distinct characteristics of NOS and scientific inquiry and the challenges in teaching about these constructs, the authors refer the reader to Flick and Lederman (2004). Recognizing the overlap of learning NOS and understanding *about* inquiry contributed to this study's research design and the nature of the interview questions.

Relationship of Teacher Knowledge, Views, and Practice

Our framework for understanding how and why a teacher teaches science as inquiry and teaches about NOS draws on the work of Shulman (1986, 1987) and Prawat (1992). Teaching science as inquiry and teaching explicitly about NOS are complex ways of teaching. Much as Shulman (1986, 1987) maintained, the nature of a teacher's actual classroom practice related to inquiry and NOS depends on a variety

Table 2 Shows the aspects of doing inquiry and their variations, from student to teacher initiated

Doing inquiry (D)	4 pts	3 pts	2 pts	1 pt
D1—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
D2—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
D3—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
D4—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
D5—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
D6—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
D7—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 from tools and techniques needed	Student given tools and techniques needed
D8—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

This matrix was used to determine who initiated the aspects of doing inquiry observed or described in teachers' lessons (described in "Methods and Data Sources") of factors including a teacher's: subject matter knowledge, views on the nature of scientific inquiry and NOS, pedagogical knowledge, as well as knowledge of the students in one's classroom. However, beyond knowledge, a teacher must also have beliefs about teaching and learning that are congruent with reform-based approaches (Crawford 2007; Prawat 1992). We view teaching science as inquiry and teaching about NOS as a type of craft knowledge, or knowledge that is rooted in one's teaching practice. This knowledge develops over time as a result a teacher's prior education, ongoing schooling, and experiences (van Driel et al. 1998) and encompasses both teacher knowledge and beliefs. The ability to successfully teach science as inquiry and teach about NOS requires a particular set of knowledge and beliefs. For example, a teacher's ability to engage students in answering scientifically oriented questions by using data as evidence, and a teacher's expertise in helping students understand that science is tentative and a product of human imagination depends on his or her own inquiry experiences, an understanding of what science is, beliefs that this is an important way to teach, as well as an understanding about the students in one's classroom. See Ackerson and Hanuscin (2007), Bryan (2003), Crawford (2007), and Luft (2001) for further description of the relationship between knowledge and beliefs and teachers' classroom practice related to inquiry and NOS. Characterizing the ways in which one teaches is a complex endeavor that requires multiple data sources and rigorous interpretation. It is certainly not enough to merely look at a teacher's self-reported views, or teacher-designed lesson plans, or even their classroom interactions, by themselves. Instead, it is necessary to take multiple factors into account when attempting to characterize one's teaching practice.

Method and Data Sources

The aim of this research was to collect and analyze teachers' statements of their views of inquiry and NOS before they participated in a PD experience and to profile each teacher's practice related to inquiry and NOS.[1] We then looked for relationships between teachers' views and their teaching practice. We employed a mixed-methods approach consisting of quantitative and qualitative data (Creswell 2009). Teaching science is a complex endeavor. The mixed-methods approach allowed us to better understand both the range and nature of teachers' views and practices. We used a number of data sources to gain a better understanding of the nature of these teachers' instruction and their views, including teachers' written descriptions of an exemplary lesson, videotape, and observations of classroom instruction, and an open-response questionnaire of views of inquiry and NOS. Additionally, we conducted interviews with a subset of the participants.

[1] This study was conducted prior to a multi-year teacher professional development program. We reported on the change in teachers' views after the professional development experience in a conference paper presented at the European Science Education Research Association. This paper is currently in review.

Context of Study

This study took place before the start of an intensive teacher PD program focused on inquiry and NOS. Thirty teachers were selected to participate from an applicant pool of more than 120, 5th- through 9th-grade teachers. Selection criteria included the following: 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, willingness to participate in the project, and evidence of a supportive school administration. Additionally, teachers were selected based on their outstanding credentials, willingness to participate in all aspects of the project, and evidence that their views on teaching were not in opposition to reform-based teaching. We selected the top 30 teachers who fit these criteria. Complete data sets were obtained for 26 of the 30 participants. From this point on, only data from these teachers will be included. Teachers had an average of 11 years of teaching experience, had taken nearly 12 college-level science courses, and reported having more than three PD experiences in science. All held teaching certificates and all but three held master's degrees, though two of the three were working on their masters at the time of the study. Moreover, most of the 7th–9th-grade teachers were teaching in their accredited field. Thus, we believed this sample of teachers consisted of some of the better prepared and motivated teachers from across the country (see Table 3) who desired to engage in an inquiry-focused experience.

Data Collection and Analysis

Nature of Teachers' Instruction

We used information from written descriptions of lessons, classroom observations and/or videotape data, and semi-structured interviews to characterize teachers' instructional practice. Multiple data sources provided a more accurate picture of what instruction looked like in each classroom. Each teacher provided a written description of an exemplary, inquiry-based lesson they taught in the last 2 years. Moreover, we observed and videotaped one to 3 h of instruction in each classroom. When we were unable to make direct classroom observations, teachers videotaped one to 3 h of their instruction to send to us. These data were collected in the spring semester, several months before the teacher PD program. Because teachers were free to select the lessons they described and we observed, we operated under the assumption that these highly motivated, conscientious teachers would select some of their best lessons. Thus, the sample lessons likely represented a best-case scenario of their instruction. We analyzed and scored the data looking first for the presence or absence of aspects of inquiry and NOS (described below). In instances where aspects of inquiry were present, we determined who initiated the inquiry (teacher or student). We also conducted semi-structured interviews with a subset of the 26 teachers to corroborate our interpretations and gain a greater understanding of the nature of their instructional practice.

Table 3 Teacher background information

Teacher	Grade level	Education	Teaching exp (yrs)	College sci courses	Research exp	Sci. PD exp	Gender
Willa	5/6	BA-Psychology*	11	4	No	1	F
Dennis	5/6	BA-Int. Relations*	4	2	No	2	M
Vanessa	5/6	BA-Psychology*	5	1	No	9	F
Wilma	5/6	AA-Literature*	4	1	No	3	F
Dani	7/8	BS-Biology*	9	16	Yes	1	F
Olive	7/8	BS-Biology*	4	23	No	3	F
Alli	7/8	BS-Biology*	5	13	Yes	3	F
Carl	8/9	BS/MA-Geology*	30	31	Yes	14	M
Trish	9	BS-Biology*	13	26	No	3	F
Ward	8/9	BS-Earth Sci Ed*	5	17	No	1	M
Amanda	5th–8th	BA-Sci Ed*	5	6	No	5	F
Albert	5th	BS-Electrical Eng.*	14	15	Yes	2	M
Brit	6th	BA-Elementary Ed*	4	3	No	0	F
Curt	8th	BA-Elementary Ed*	9	10	Yes	1	M
Caelyn	5th	BS-Elementary Ed	2	7	No	2	F
Darlene	7th	BA-Fine Arts*	10	7	Yes	4	F
Flo	6th	BS-Education*	19	4	No	8	F
Gabby	8th	BA-Anthropology MA-Museum Stud	5	16	No	3	F
Paula	6th–8th	BS-Elementary Ed*	22	9	No	3	F
Kendra	7th	BS-Biology*	5	16	Yes	0	F
Kari	5th	BA-Education*	20	2	No	3	F
Kate	7th	BS-Chemistry*	3	14	No	1	F
Olga	5th	BS-Education*	23	1	No	1	F
Pris	7th	BA-Bio/Chem MA-Bio-Geography	22	32	Yes	4	F
Pam	7th	BS-Elementary Ed	32	7	No	10	F
Ron	8th	BS-Science Ed M.Ed-TESOL	2	21	No	1	M
AVG			11.0	11.7		3.4	

* Denotes a master's degree in education

Presence of Inquiry and NOS

To analyze teachers' instruction, we reviewed written descriptions of their lessons, our field notes from classroom observations, and video recordings, taking several passes through the data. We applied an a priori coding scheme identifying the presence (1) or absence (0) of inquiry (developed from NRC 1996, 2000) and NOS (developed from Lederman et al. 2002) in each lesson. We used the codes to develop numerical scores for aspects of doing inquiry and understandings about inquiry and NOS present in teachers' sample lessons (see Table 1 for a complete list of codes). Because there was some overlap between the eight abilities to do inquiry and the five essential features of inquiry, we merged these elements together. The result was a list of eight aspects of doing inquiry. Aspects of doing inquiry needed to be observed only once in a lesson to be recorded as present. Teachers received a score from zero to eight on a given lesson depending on how many of the eight aspects of doing inquiry were observed or described in the lesson. For example, if a teacher only had her students to use a triple-beam balance to collect data during a lesson, we coded this as D7 (i.e., using tools or techniques to gather data), indicating that one of the eight aspects of doing inquiry was present in the lesson. Scores for understandings about inquiry and understandings about NOS ranged from zero to seven, since there were seven aspects for each of these categories. Again, we determined the scores based on the presence or absence of these features observed or described in the lesson. We also noted if understandings about inquiry and NOS were addressed explicitly or implicitly by teachers. In situations where the presence or absence of aspects of inquiry or NOS was unclear, we used member checking to verify our interpretation. The final decision in these situations was made by consensus through discussion among a group of five science education researchers.

Who Initiated the Inquiry

To establish who initiated aspects of doing inquiry observed or described in teachers' lessons, we combined Table 2–6 from *Inquiry and the National Science Education Standards [INSES]* (NRC 2000) with the Inquiry Analysis Tool (Bell 2002). In doing so, we created a matrix that could be used to determine whether observed aspects of inquiry were either student or teacher-initiated. We used a numerical score from 1 to 4 to describe who initiated aspects of doing inquiry; 1 being the most teacher-initiated and 4 being the most student-initiated (see Table 2). Thus, if a lesson included all eight aspects of doing inquiry, and each was completely student-initiated, the lesson scored 32-points, whereas a lesson that lacked aspects of doing inquiry scored zero-points. In situations where who initiated inquiry was unclear, the final decision was made by consensus as described above.

Characterization of Inquiry Instruction

After establishing the presence of inquiry and who initiated the inquiry for all 26 teachers' sample lessons, we plotted each teacher's highest score (across the available data sources) 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" or "not having" a robust ability to teach science as inquiry, based on their position along the continuum. We then purposefully selected eight teachers to interview from the group who did not demonstrate a robust ability to teach science as inquiry. These teachers were selected to encompass the range of teachers not using inquiry-based instruction in their classrooms. We used a semi-structured interview to corroborate our interpretations and gain a greater understanding of the nature of their instructional practices (the interview is available in the supplementary materials A).

Characterizing Teachers' Views of Inquiry and NOS

Teachers' views of inquiry and NOS were assessed using a validated, open-response, views questionnaire. We developed the questionnaire over a period of 2 years drawing on elements of inquiry defined in *INSES* (NRC 2000) and aspects of NOS reported to be accessible in K-12 classrooms (Lederman et al. 2002). We developed our scoring scale after Lederman et al. (2002); however, we modified the original from a two-point scale (differentiating naïve from more informed views) to a four-point scale based on the teachers' views of inquiry and NOS (0-uninformed, 1-emerging, 2-more informed, 3-robust). The four-point scale was finer grained and more clearly highlighted variance in views of inquiry and NOS across the population of teachers (see Table S1 in supplementary materials B for a list of the views of inquiry and NOS items and the scoring rubric). The Cronbach's alpha value for the questionnaire lies within the good range ($\alpha = 0.88$). Initially, each item was scored independently by two researchers. Throughout the process, the coders consulted with one another to ensure agreement. Next, we analyzed 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. We then conducted a horizontal analysis for each individual item across our participants, to ensure consistency and to fine-tune the scoring rubric. Interrater agreement approached 95 %. When there was a disagreement, we discussed it until we reached consensus. Finally, we ran a simple linear regression to determine whether there was a relationship between views of inquiry and views of NOS.

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 correlated scores of the presence of inquiry with scores of views of inquiry and views of NOS. We also looked for evidence of a relationship between views and practice in semi-structured interviews of eight of the teachers.

Findings: Characterizing the Nature of Teachers' Instruction and Practice

Presence of Inquiry and NOS

Doing Inquiry

Analyses of multiple data sources revealed that across the participants, there was a great deal of variation in instructional practice related to inquiry-based teaching. The variation was particularly evident in the presence or absence of *abilities to do inquiry* and *essential features of inquiry*. These aspects of doing inquiry were easily identified because they related to what the learner was doing in the classroom. In some classrooms, all eight aspects of doing inquiry were observed or described. Whereas in other classrooms, none of the eight aspects of doing inquiry were noted

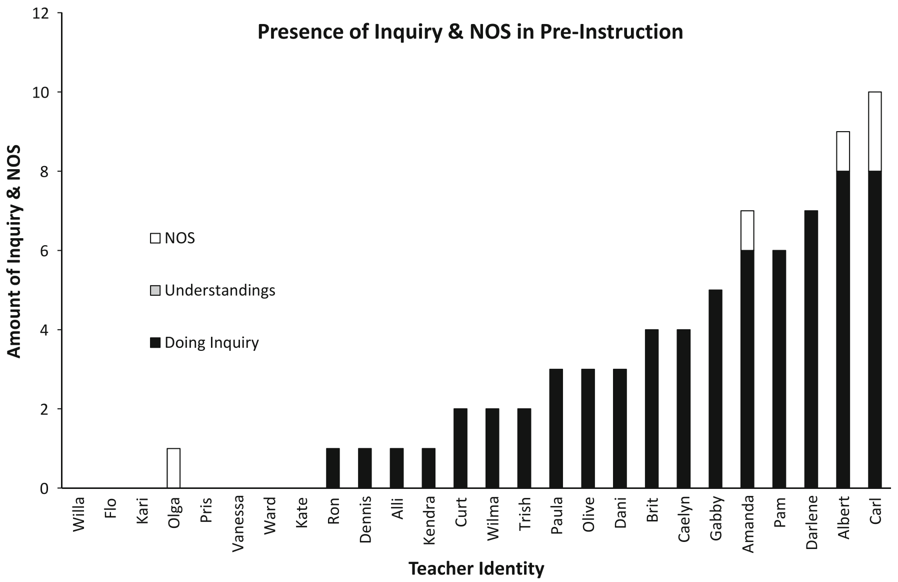

Fig. 1 Shows the amount of the aspects of doing inquiry, understandings about inquiry, and aspects of NOS present in one lesson selected by a teacher prior to participating in the program. *Values* on the *y*-axis correspond to the number of aspects of doing inquiry, understandings about inquiry and NOS identified in a particular individual lesson

(see Fig. 1). In general, it was clearly evident that the majority of these teachers were not using many aspects of doing inquiry in their instruction.

In only six teachers' instruction did we find evidence of widespread use of inquiry (i.e., over half of the eight aspects were present). In these classrooms, teachers engaged their students in investigations centered on scientifically oriented questions and data collection. Four of the six teachers provided opportunities for their students to use data they collected as evidence to answer scientifically oriented questions and share their data with others. An example of this was described by Darlene.

> They [students] raise questions that might be answered by doing an experiment. They design their working in groups of three or four. After their experimental plan is approved, they conduct their experiment, recording data, controlling variables, making 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. (Application materials)

In this excerpt, Darlene described how she engaged her students in many aspects of doing 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 in the data, including interpretation and sharing with others, occurred in three other classrooms. For the remaining two teachers whose lessons exhibited multiple aspects of doing inquiry, the focal point was primarily on data collection and not on the interpretation or 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.

Gabby: What would you say about breathing rate before and after? How would you summarize this? Breathing before and breathing after?
S1: It got faster
Gabby: What about our hypothesis? Did we prove or disprove our hypothesis?
S2: Proved it
Gabby: 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?
S2: We're tired
Gabby: Okay, we're tired, that's one thing. What do we need if we are more tired?
S3: We need more air
Gabby: What is in the air we breathe in?
S4: Oxygen
Gabby: Right. Oxygen gives us more energy. (Classroom observation, 5-19-09)

This interaction took place at the very end of the period and was cursory in nature. Moreover, the questions Gabby asked her students were mostly superficial; she did not appear to push her students to make interpretations of the data; rather she made most of the interpretations for them. In an interview conducted with Gabby, she stated she did not believe her students were prepared to interpret data on their own and needed support. 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" (Interview, 8-6-09).

In most cases, few aspects of doing inquiry were evident in lessons. Those aspects that were common were the more basic abilities to do inquiry, 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 and S-waves in order to determine when a locale would feel the effects of an earthquake. However, there was no evidence these teachers engaged their students in anything beyond basic abilities to do inquiry that are similar to process skills. In several classrooms, we found no evidence of aspects of doing inquiry. It is likely these teachers may engage their students in certain aspects of doing inquiry from time to time, but we saw no evidence of this in the lessons they chose to highlight.

Understandings About Inquiry

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

Nature of Science

There was limited evidence of NOS instruction (see Fig. 1). We observed NOS instruction in only four classrooms. In each of these classrooms, the teachers included implicit references to NOS, but did not explicitly discuss NOS with their students. For example, Carl, a veteran teacher with 30 years of teaching experience, mentioned the tentativeness of scientific knowledge when discussing how far geophysics has come since the early days of seismographs. Carl 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. Carl 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. (Classroom observation, 5-20-08)

Here, Carl alluded to the subjective nature of scientific knowledge, 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 evidence in the submitted materials. 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 nature of scientific knowledge in relation to Pluto's change from planet to planetoid. Although his students gave him the perfect opening to do so on at least three occasions, he did not take the opportunity to do so.

Who Initiated the Inquiry?

Numerical scores for who (teacher or student) initiated aspects of doing inquiry in teachers' lessons ranged from 0 to 25, the higher the number, the more student-initiated the inquiry. Twenty-two of the twenty-six teachers scored 12 or less, suggesting that most inquiry observed in lessons was teacher-initiated. The eight teachers' lessons that contained no aspects of doing inquiry were scored a zero, even if the lesson appeared student-centered. These included lectures and activity-based lessons. Several of these lessons were PowerPoint presentations that were used to relay information to students. Because there was no evidence of doing inquiry in these lessons, we do not discuss them further. Of the remaining teachers' lessons, most (14/18) scored 12 or below. These lessons were considered more teacher-initiated with respect to inquiry (see Table 2). Only four of lessons were considered more student-initiated.

The lessons characterized as having more student-initiated inquiry were all investigations that provided students with at least some autonomy or intellectual ownership. For example, Albert and his students were working with a local biologist to collect data for a national database used by scientists. At the same time, Albert engaged his students in a classroom investigation focused on explaining the migratory patterns of particular bird species. His students compared presence and absence data they collected at a local wetland to data collected from other sites across the country. After entering the data into the database, his students produced reports to explain patterns they saw in the data. Each student chose the information he or she wanted to include in the report. Another teacher, Paula, described a series of lessons in which 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 and Darlene both described lessons in which their students engaged in full inquires; the students determined the question. In both cases, the teacher acted as a guide, supporting the students in their inquiries.

The lessons characterized as having more teacher-initiated inquiry included 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. 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 and demonstrated 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 laboratory instructions, she circulated, giving advice and talking with students. Several times she was overheard telling her students exactly what they should be doing and seeing. An example of this was, “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” (Classroom observation, 5-10-08). Three investigations were categorized as more teacher-initiated. In 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 materials they would need, guided students through collecting data, and helped them answer questions on a worksheet. Similarly, Gabby had her students investigate, “What will happen to our breathing after we exercise?” During this investigation, Gabby 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.

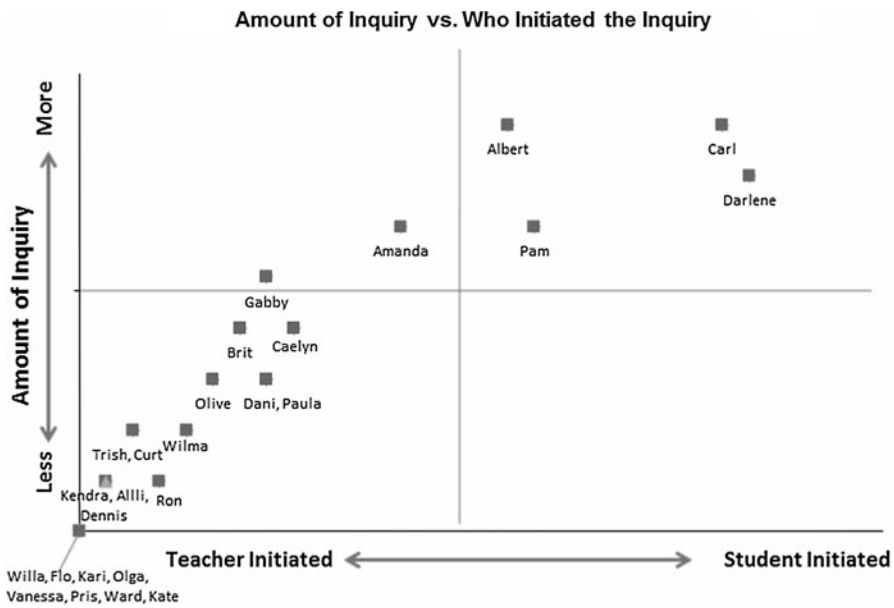

Fig. 2 Amount of inquiry versus who initiated the aspects of inquiry observed in the lessons. *Values* on the *y*-axis correspond to the number of aspects of doing inquiry identified in a particular individual lesson

Characterization of Inquiry Instruction

Figure 2 displays teachers' scores for the amount of inquiry (aspects of doing inquiry only) versus who initiated the inquiry. Most of the teachers' lessons plot in the lower left quadrant of Fig. 2, while only a few teachers' lessons plot in the upper-right quadrant. The four teachers in the upper-right quadrant demonstrated or described 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 other teachers' lessons. However, the lack of inquiry in several lessons does not necessarily mean these teachers did not routinely teach science as inquiry. Because the data used to characterize classroom instruction were limited to teachers' descriptions of their lessons and at most 3 h of classroom observations, 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). We did this to corroborate our placements and to gain a better understanding of these teachers' instructional practice related to inquiry.

Teachers were asked a series of questions about inquiry-based instruction, as practiced in their classrooms. 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 as defined in reform-based documents. Six of eight teachers identified or described lessons that contained very little inquiry. These lessons were mainly 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. Ron 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" (Interview, 8-6-09). Based on observational data, all but two of these six teachers plotted in the lower left-hand quadrant of Fig. 2. Thus, for the most part, classroom observations and teacher interviews corroborated one another suggesting that inquiry-based instruction was not very common across these teachers. The two teachers' lessons that included several aspects of inquiry were from an ecosystems and gardening unit. In the ecosystem unit, Brit'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. 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 anticipated that might be common in instruction. We analyzed these questions to determine whether teachers were using the features of inquiry, even though they might not have been able to articulate the nature of their instruction. Analysis of the questions revealed that inquiry was not common in most of the teachers' instruction; and when it was present, it was teacher-directed. For instance, when asked about engaging students in scientifically oriented questions, only one of the eight teachers was able to describe an instance where she helped students develop questions to investigate. Caelyn shared,

> During our human body unit we asked questions when we are doing the circulatory system 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. (Interview, 8-6-09)

Four of the remaining teachers shared that they did not have students answer scientifically oriented questions. Interestingly, in one case, a teacher claimed, "No, I've never done that." Interview, 8-6-09, Gabby) even though she clearly had in one of the lessons we observed, suggesting she did not have a good understanding of what a scientifically oriented question was. 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. Another teacher 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 the use of scientifically oriented questions. Six teachers described having students collect data, graph data they collected, and explain what it means. These exercises were mostly teacher-directed. Confirming this, Gabby 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. (Interview, 8-6-09)

The remaining two teachers, both elementary teachers, also had students work with data. One had 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). 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. One teacher cited an example of how her students shared findings from a study of their school garden with the rest of the school. The students used findings to decide what they would do with their garden. Many of the other teachers reported having students "share out" with other groups. However, most of their descriptions did not relate to sharing and defending findings, but instead related to students sharing ideas they discussed in class. For instance, Flo explained she had students share their findings with parents at a science night. Students sang songs and made up raps about rocketry. As an example, "They talked about Goddard, the originator, and the science behind it [rocketry], 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" (Interview, 8-5-09). This description implies students 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, but volunteered this was something they would like to do.

Based on interviews with those 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 these teachers described using in their classrooms was having their students collect or manipulate data. 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 multiple aspects of inquiry in their teaching. When present, the nature of the instruction tended to be more teacher-initiated. Revisiting Fig. 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 instruction that included aspects of doing inquiry. In a small number of the classrooms, many of these aspects of doing inquiry were present, whereas in the majority of the classrooms, there was little or no evidence of abilities or features of inquiry. The most common aspects of doing inquiry were the basic abilities, such as using tools and mathematics in science class. Instruction related to understandings about inquiry was 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. All instances of NOS instruction were implicit. The amount of student-initiated inquiry was fairly low, suggesting that inquiry was, for the most part, 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 participants confirmed our analysis of classroom observations and descriptions of teachers' lessons.

Characterizing Teachers' Views of Inquiry and NOS

Views of Inquiry

Analysis of the views instrument showed that teachers held a range of views of inquiry and NOS. In general, this group of highly motivated and well-qualified teachers demonstrated fairly limited understandings of inquiry ($M = 0.87$)—falling between the uninformed and emerging categories (see Fig. 3). Five of 26 teachers held uninformed views for all three items, while seven held uninformed views on two of the three questions. Only two teachers held informed or robust understandings on each of the items related to inquiry. When asked (item 6) to articulate what inquiry-based science teaching was, only five teachers gave informed or robust responses. The remaining 21 teachers were characterized as holding uninformed or emerging views. Most teachers (16) gave responses that were considered uninformed. Item 6 had the lowest mean of any of the items on the instrument ($M = 0.65$). A typical uninformed 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 questionnaire, 8-9-08)

Two teachers' responses to this question were scored as robust. Their views of inquiry conformed to those of inquiry espoused by the *NSES*. One of these teachers stated,

> 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 questionnaire, 8-9-08)

In his response, Carl demonstrated an understanding of the balance between student and teacher-directedness and the importance of using data as evidence in developing explanations.

In response to item 7 about the scientific method, most teachers (21/26) held uninformed or emerging views. The mean score on this item was slightly below emerging ($M = 0.96$). 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 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 understanding of the ability to do scientific inquiry. The item asked participants to describe how a scientist might investigate how organisms or climate changed throughout the geologic past. The mean score fell in the emerging category ($M = 1.00$). Eighteen teachers scored uninformed or emerging. Many teachers were able to state what kinds of data might be collected, but had trouble explaining what one would do with the data once collected.

Data from interview questions related to teachers' views of inquiry corroborated teachers' written responses. Few teachers verbally articulated robust or informed views of inquiry. Those teachers that did articulate informed or robust views of inquiry in the interview also demonstrated more robust views on the questionnaire. For example, even though Kendra struggled in describing inquiry-based instruction, she demonstrated more robust views on other aspects of inquiry. 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 that go with those pieces are critically important to being a scientist, and thinking like a scientist, and acting like a scientist but 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. (Interview, 8-5-09)

Amanda, a teacher having uninformed views of inquiry, believed the scientific method to be fairly rigid. Amanda shared,

> We talk about how you use the scientific method everywhere even to cross the street. 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. (Interview, 8-6-09)

Views of NOS

Views of NOS also varied across the sample; however, the mean score on these items was higher than the mean inquiry score ($M = 1.40$ as opposed to $M = 0.87$), falling in the emerging category. Although no teacher scored uninformed on all five NOS items, four teachers scored either uninformed or emerging on all NOS-related items. Four other teachers scored informed or robust on all five items. The two lowest scoring NOS items were items 1 and 3 ($M = 0.92$ and $M = 1.10$). On item 1, the mean fell in the emerging category and 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 responded that either there were a variety of ways to do science and did not elaborate on this or that all science was experimental. The mean score on item 3 ($M = 1.10$) was slightly above the emerging level. Here, most teachers understood that different scientists have 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 mean score on item 5 ($M = 2.30$) that dealt with understanding the difference between observations and inferences and the importance of both in the development of scientific knowledge. For this aspect, most teachers (22/26) held informed or robust views. In general, these teachers were able to describe the difference between an observation and an inference 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 questionnaire, 8-9-08) and connecting them to the development of scientific knowledge.

Relation Between Views of Inquiry and Views of NOS

Results from a Spearman rank correlation indicated there was an association between teachers' views of inquiry and views of NOS ($r_s = 0.68$). This relationship was statistically significant ($p < 0.001$).

Summary

Teachers' views of inquiry and NOS varied from uninformed to robust for each item. The mean inquiry score ($M = 0.87$) suggests these teachers held fairly limited views of inquiry. Teachers scored the lowest on an item that asked them to describe inquiry-based instruction. For NOS, the mean score ($M = 1.40$) was slightly higher than the mean 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 of inquiry and NOS.

Relation of Views to Classroom Practice

Analysis of the data indicated that teachers who employed multiple aspects of inquiry in their instruction held more informed views of inquiry and NOS while

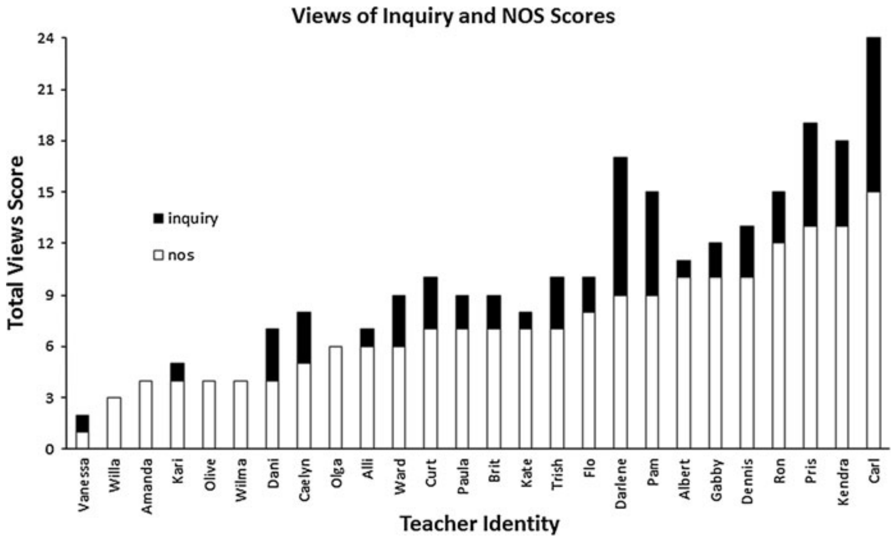

Fig. 3 Teachers' views of inquiry and NOS measured by the views questionnaire

teachers who employed fewer aspects of inquiry held less-informed views of inquiry and NOS. This pattern can be observed in Figs. 1 and 3. Teachers who plotted on the right side of Fig. 1 (e.g., Carl, Albert, Darlene, and Pam) also tended to plot on the right side of Fig. 3, whereas teachers who plotted in the middle or on the left side of Fig. 1 plotted in a similar place on Fig. 3. This pattern was clear for the majority of teachers. Two teachers showed the opposite pattern from the rest of the group (see Amanda and Pris in Figs. 1 and 3). These teachers were excluded from the following analysis. Results from a Spearman rank correlation indicated an association between teachers' views of inquiry and their inquiry teaching score ($r_s = 0.44$), and between their views of NOS and their inquiry teaching score ($r_s = 0.43$). These relationships were statistically significant ($p < 0.05$).

Interestingly, when asked whether lessons they described and we observed represented inquiry-based instruction, all eight teachers 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 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). Teachers rarely mentioned aspects of inquiry congruent with those defined in reform-based documents. Only four teachers used words or phrases that may have indicated inquiry. One teacher made the following comments throughout her interview, "Students making observations and drawing conclusions", "students experimenting and classifying", "students hypothesizing", and "students guessing based on their observations" (Brit, interview, 8-6-09). Furthermore, five of the eight teachers verified that the lessons we observed, which had little evidence of inquiry, were fairly representative of their practice. 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 both teachers' inquiry-based teaching practice and their views of inquiry 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 the apparent lack of empirical evidence for what is actually happening in classrooms across the United States, pertaining to the presence or absence of inquiry and NOS. Our aim was to provide empirical evidence for the presence or absence of inquiry and NOS instruction, assess teachers' views of inquiry and NOS, and look for relationships between their views and practice.

Nature of Teachers' Instruction

Inquiry

By analyzing classroom observations and descriptions of lessons of 26, 5th–9th-grade teachers, we found a wide range of instructional practices, related to the aspect of doing inquiry. This variation was not surprising given the different backgrounds of the teachers. 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. On the one hand, one might expect a teacher who had science research experience to be able to teach science as inquiry, yet one of the four teachers who demonstrated an ability to teach in this way had no research experience. On the other hand, 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 teaching and learning science. Each of these teachers taught for a minimum of 10 years, took at least seven, if not many more university science courses, and either had multiple science PD 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 aspects of doing inquiry beyond the use of fairly simple process skills and at times, the collection of data. Inquiry is a central science teaching strategy and is advocated in reform-based documents. Given that the focus of the PD program would be on inquiry, and teachers had the freedom to select the lessons described and observed, we expected these teachers would select some of their better lessons as a best-case scenario of their practice. Consequently, we believe, if anything, our analyses likely exaggerated 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 make the assumption that inquiry-based instruction is probably even less common in the population of 5th–9th-grade teachers across the country. In other words, the state of affairs related to inquiry-based teaching may be even more dismal than it appears in this study.

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

NOS

Generally speaking, instruction related to NOS was not very common in the lessons we analyzed. There were only a few instances of implicit instruction, and no explicit NOS instruction. Implicit instruction is not enough to support learners in understanding NOS (Lederman 2004). The literature on NOS expresses the importance of explicit instruction in supporting learners in developing conceptions of NOS consistent with those advocated by science education reform documents (Abd-El-Khalick and Lederman 2000). The paucity of instruction related to NOS and the complete lack of evidence of explicit NOS instruction are troubling. NOS is a well-researched topic in science education. Numerous 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. Since inquiry-based instruction can provide a rich context to teach about NOS, it might be assumed that more inquiry-based instruction might lead to more instruction about NOS.

Views of Inquiry and NOS

Analysis of the views of inquiry and NOS questionnaire revealed a range of understandings across the 26 teachers. However, most of these teachers held fairly limited views and misconceptions on inquiry and NOS. In particular, many of these teachers believed that scientists follow a uniform series of steps that are experimental in nature, allowing little or no room for creativity. But even more distressing was that very few of these well-qualified teachers could describe what inquiry-based instruction actually was. Interviews conducted with eight of the teachers confirmed this. Teachers with inadequate views of 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 NOS scores suggests that more informed views of one may result in more informed views of the other. This association highlights the importance of supporting teachers in learning about both inquiry and NOS. Science education reform documents that propose or describe using teaching strategies like inquiry, and teaching concepts like inquiry and NOS, are now ten to 20 years old or older (e.g., AAAS 1989; NRC 1996). It is disconcerting to learn that many teachers appear unfamiliar or struggling with these ideas. The fact that most 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

Data analyses indicated an association between teachers' views and classroom practice. That is, teachers with more robust views were more likely to teach science as inquiry, whereas 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 NOS and inquiry teaching practice. Teacher knowledge affects classroom practice (Cochran-Smith and Lytle 1999). Many teachers in this study held limited views of inquiry, and 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 of these teachers. All eight interviewed believed they were teaching science as inquiry at least some of the time. However, 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 NOS is not easy. Previous research has identified a number of external and internal factors that may prevent teachers from incorporating these reform-based teaching strategies. Some of the factors external to the teacher include lack of time (Abell and McDonald 2004), concerns over financial constraints (Abell and Roth 1992; Ginns and Watters 1999), lack of administrative or community support (Lee and Houseal 2003), and classroom management issues (Roehrig and Luft 2004). Whereas common factors internal to the teacher include a lack of content or pedagogical knowledge (Gess-Newsome 1999; Shulman 1986) and beliefs that are inconsistent with teaching in this way (Prawat 1992; Roehrig and Luft 2004). In choosing a population of highly motivated and well-qualified teachers, with views on teaching congruent with reform-based teaching approaches and 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 in this study are the most reasonable explanation 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 implies a disconnect between teachers' views of inquiry and their actual practice.

There are a few methodological limitations that need to be considered in the interpretations of this study. There was a relatively small sample size ($n = 26$). This makes generalization difficult. However, these teachers were selected from a pool of highly motivated teachers, thus we argue they could represent a best-case scenario of what teachers know and what teachers are doing in their classrooms. We also recognize that a skillful teacher will not use inquiry in every lesson; it is not appropriate. Although we were only able to observe a few lessons of each teacher, the teachers chose the lessons we observed. We assumed these teachers selected some of their better, more reformed-based lessons. Moreover, we asked participants to describe some of their better lessons and conducted interviews with a subset of the teachers to ensure our interpretations were in fact consistent with teachers' descriptions of their instruction. Consequently, we believe our interpretations to be as accurate a depiction as possible, of what was occurring in these teachers' classrooms. This being said, we do see the necessity of a future study that observes a larger population of teachers to provide a more representative analysis of teachers' views and their practice related to inquiry and NOS.

Conclusions and Implications

Although reform documents in the United States highlight the importance of inquiry and NOS and refer to inquiry as a central teaching strategy, this study shows that relatively few teachers, from a group of highly motivated teachers, were actually teaching science as inquiry or about NOS. Although researchers have anecdotally reported on the lack of inquiry-based teaching, and there is some information from surveys given to teachers on this matter, we believe this study is one of few providing actual classroom-based evidence for this claim. It was particularly troubling that many of the teachers in this study believed they were teaching science as inquiry even when they were not. This calls into question the impact of reform-based documents like the standards. If some of the best teachers we could recruit failed to demonstrate an understanding of inquiry-based instruction and did not teach science as inquiry, than who does? We want to be clear that the blame does not rest on the teachers. With the recent release of *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012), and new science standards close at hand, it is important to consider how we can better support teachers in understanding and enacting reform-based teaching approaches. The findings from this study point to the critical need for first, a unified conception of inquiry-based instruction; second, rigorous assessments that go beyond teacher self-report; and third, PD that supports teachers in learning about inquiry and NOS and in enacting reform-based instruction in their classrooms.

Inquiry has been a buzz word in science education for many years; however, there is still no consensus as to what it actually is and what it looks like in the classroom (Anderson 2002). If the academic community has not reached consensus, how can we expect teachers to understand what inquiry is and how to teach science in this way? The use of scientific practices in place of the essential features and abilities to do inquiry in the most recent framework is a good start, but it is not enough. We need to gain a better understanding of how reform documents impact what teachers' know and how they teach. Some important questions that need to be considered are: Do teachers and preservice teachers read national and state standards documents? If so, are they given adequate time and support to reconstruct their understandings and practices to more closely align with these documents? If not, how is information from these documents relayed to them? In addition, it will be important to understand how teacher education programs and professional development providers integrate aspects of the latest reform effort, such the focus on scientific practices, into their existing frameworks? We need more empirical research into the ways teachers receive and interpret information from reform-based documents. The word inquiry is used in a variety of contexts. Without adequate support, these meanings can become easily lost or misunderstood. If these issues are not addressed, we fear we will find ourselves in a similar place 10 years from now, where even the best teachers are not engaging their students in scientific practices or teaching about NOS.

The fact that many teachers believed they were teaching science as inquiry, but in reality were not, further demonstrates that teacher self-report alone fails to give an accurate picture of actual classroom practice. If teachers cannot articulate exactly what inquiry is, then it stands to reason that simply reporting one's perception of using inquiry in one's teaching practice is not reliable. This highlights the need for better assessments to characterize teachers' instruction related to inquiry and NOS (Capps et al. 2012). At present, there are a variety of general classroom observation protocols used to assess reform-based teaching approaches (e.g., Reformed Teaching Observation Protocol, Inside the Classroom Observation Protocol, Instructional Strategies Classroom Observation Protocol), but far fewer that specifically assess inquiry-based teaching and NOS. Thus, there is a need to develop observation and interview protocols that focus solely on these features. In this study, we used aspects of inquiry as defined in the standards (NRC 1996, 2000) and aspects of NOS suggested by Lederman et al. (2002) to develop our interview and observation protocols that were useful in making comparisons across the teachers involved in our study. Another promising effort underway to quantify inquiry-based instruction is the Education Development Center's Inquiry Science Instruction Observation Protocol [ISIOP] (Minner et al. 2010). We suggest these are good first steps; however, as the new science education standards are established, it may be fruitful to develop new protocols using the new standards.

Reaching a consensus on the nature of inquiry teaching, taking care, and precision in communicating what inquiry is to members of the education community, and developing viable and usable assessments of inquiry and NOS are important first steps. However, these first steps are not enough. Teaching science as inquiry and explicitly teaching about NOS are complex and sophisticated instructional approaches that demand significant PD (Crawford 2000, 2007). Teacher educators will need to facilitate teachers in articulating their views of inquiry and NOS and support them in comparing how their views relate to conceptions of inquiry and NOS articulated in reform documents. Teachers will also need opportunities to both engage in their own inquiries and practice teaching science as inquiry and about inquiry and NOS. This support should begin early in preservice teacher education with authentic inquiry experiences (Windschitl 2002) and continue as part of inservice professional development. If we expect teachers to use new instructional approaches, they will need to have well-designed, ongoing opportunities to learn and teach in this way (Loucks-Horsely et al. 2003).

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