

SUPPORTING TEACHERS IN LEARNING ABOUT INQUIRY, NATURE
OF SCIENCE, AND IN TEACHING THROUGH INQUIRY

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SUPPORTING TEACHERS IN LEARNING ABOUT INQUIRY, NATURE OF SCIENCE, AND IN TEACHING THROUGH INQUIRY

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Inquiry-based instruction and instruction about nature of science (NOS) are central to reform-based science teaching. Professional development (PD) is a well-recognized way to support teachers in learning about and using new pedagogical approaches. At present there is a lack of information regarding what teachers learn during inquiry PD programs, if this learning impacts their teaching, and evidence linking teacher learning to student learning. To begin addressing these issues, first, I conducted a critical review of the literature on teacher PD. I analyzed 17 PD programs supporting teachers in learning about inquiry to determine the extent to which they aligned with features of effective PD outlined in the literature. I then critiqued the outcomes of the studies based on the methods employed by the researchers. Findings suggested a general alignment with recommended features of effective PD with a few notable exceptions, including: supporting teachers in developing inquiry-based lesson plans, providing authentic inquiry experiences, and focusing on science content for teachers. The review also revealed that no study connected participation in inquiry PD with all the desired outcomes of teacher PD: enhanced teacher knowledge, change in beliefs and practice, and enhanced student achievement. Second, I examined the teaching practice and views of inquiry and NOS of a group of highly-motivated teachers before their

participation in an inquiry PD program. Findings indicated most teachers held limited views of inquiry-based instruction and NOS. Moreover, most teachers used primarily teacher-centered instructional practices and elements of inquiry were observed in less than half of the classrooms. The study provided empirical evidence for the claim that even some of the best teachers struggle to enact reformed-based teaching. Further, it highlighted the critical need for an agreed upon definition of inquiry-based instruction and rigorous PD to support teachers in learning about reform-based teaching. Third, I examined science content knowledge and views of inquiry and NOS of a group of 5th-9th grade teachers before and after participating in an inquiry PD. Analysis of pre and post-program instruments indicated project teachers showed greater gains in subject matter knowledge than comparison teachers and the relative change was significantly different statistically. Additionally, most project teachers demonstrated a shift from less informed to more informed views of inquiry and NOS. Finally, analyses of post-program questionnaires and interviews indicated that supporting teachers in reflecting on the relationship between their classroom teaching practice, and new knowledge acquired during PD, may be an important link in enhancing teacher knowledge to changing practice. A future study will follow several participant teachers into their classrooms after the PD in order to understand how the PD experience impacted their teaching.

BIOGRAPHICAL SKETCH

Daniel grew up in Downers Grove, Illinois. He attended Hope College in Holland, Michigan where he earned a degree in geology with a minor in Spanish in 1998. Following graduation he worked as a substitute teacher and tutor in the suburbs of Chicago. In 1999 Daniel walked the Appalachian Trail with his girlfriend Krista. After the Trail, Daniel earned Master's degrees in geology and education from Indiana University in Bloomington, Indiana. He then moved with his wife, Krista, to Honduras where they served as natural resource volunteers in the Peace Corps. Upon returning to the US, Daniel taught physics and astronomy in California and 8th grade physical science in Newfield, NY. In August, 2007 Daniel entered the PhD program in Learning, Teaching, & Social Policy at Cornell University where he worked with Dr. Barbara Crawford on the Fossil Finders project. Daniel accepted a tenure track faculty position at the University of Maine in Orono, Maine where he will begin as an Assistant Professor in the College of Education and Human Development in the fall of 2011.

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CHAPTER 1

INTRODUCTION

Over the past several decades there has been some concern over science and math scores in the United States (US). Test results from the Trends in International Mathematics and Science Studies (TIMSS) and the Program for International Student Assessment (PISA) have indicated that U.S. students are falling behind students from other developed nations. The slide in science generally begins at the middle level and is more pronounced by high school. Science education reform documents advocate using an inquiry-based approach to science teaching (American Association for the Advancement of Science [AAAS] 1989, 1993; National Research Council [NRC] 1996, 2000). Inquiry-based instruction shifts the focus from the memorization of facts and concepts and focuses on students seeking answers to scientifically-oriented questions. Inquiry-based activities are thought to have positive effects on students' science achievement, cognitive development, and interest (Chang & Mao, 1998; Ertepinar & Geban, 1996; Geban, Askar, & Ozkan, 1992; Gibson & Chase, 2002). Moreover, inquiry-based instruction provides a context to teach about the nature of scientific knowledge [NOS] (Schwartz, Lederman, & Crawford, 2004) another important science teaching objective endorsed by reform-based documents. Unfortunately, most teachers do not routinely use inquiry-based instruction or teach about NOS due to a number of issues including: perceived time constraints due to high-stakes testing; unfamiliarity with how science is practiced (Deboer 2004) or the nature of scientific knowledge (Lederman, 1999); inadequate preparation in science

(Krajcik, Mamlok, & Hug 2000), or they simply do not understand what inquiry and NOS are. The absence of inquiry-based instruction and instruction about NOS is more apparent at the elementary and middle school levels, where teachers often have little or no formal science training and lack familiarity with the fundamentals of scientific inquiry, inquiry-based instruction (Kennedy 1998; Loucks-Horsley, Hewson, Love, & Stiles, 2003), and NOS (Lederman, 1999). Inquiry-based instruction and teaching about NOS are complex and sophisticated ways of teaching that demand significant professional development [PD] (Crawford, 2000; 2007; Lederman, 1999). It is hard to teach in a way one has never learned. Thus, without effective PD that supports teachers in learning about inquiry and NOS, and learning science subject matter knowledge, it is unlikely that teachers will have adequate knowledge to enact reform-based teaching in their classrooms.

In order to support teachers in learning about inquiry and NOS and enacting reform-based teaching in their classrooms we developed the Fossil Finders project. Fossil Finders: Using Fossils to Teach about Evolution, Inquiry, and Nature of Science was a multi-year National Science Foundation (NSF) funded project¹. The project had the following goals: 1) creating an authentic context to enhance children's and teachers' understandings of NOS and evolutionary concepts, 2) motivating children to learn more about science, and 3) developing educational materials that help teachers and children understand inquiry. The centerpiece of Fossil Finders was an authentic scientific investigation aimed at reconstructing the environment of the Devonian Period in central New York. An innovative, two-year PD program was

¹ NSF Grant Proposal, Award # DRL-0733223, January 1, 2008 p. 1

designed and carried out with two separate groups of teachers (Pilot Group 1 & Pilot Group 2). The PD was combined with the development of innovative curriculum materials, the creation of a website and database, and the opportunity for teachers and students to work with paleontologists on an authentic scientific investigation. A central focus of the PD was to support teachers in learning science content knowledge so they could later enact the curriculum and conduct the investigation with their students. The PD program targeted three areas: inquiry-based teaching strategies, nature of science, and geology and evolutionary concepts. Teachers engaged in the curriculum and investigation from the perspective of learners and were supported in translating what they learned into their classrooms.

The chapters in this dissertation include: a critical review of the literature on inquiry-based professional development (Chapter 1), which was used to help design the teacher PD experience; a study documenting teachers' views on inquiry and NOS and their teaching practice prior to their participation in the Fossil Finders project (Chapter 2); and a study that examines changes in teachers' subject matter knowledge and views of inquiry and NOS after participating in Fossil Finders (Chapter 3). A future study, not included in this dissertation, will follow several of the Fossil Finders teachers into their classrooms, after the PD, in order to understand in what ways the PD experience impacted their classroom teaching practice.

References

- American Association for the Advancement of Sciences. (1989). *Project 2061: Science for all Americans*. New York: Oxford University Press.
- American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*.
- Chang, C.Y., & Mao, S.L. (1998). The effects of an inquiry-based instructional method on earth science students' achievement. (ERIC document reproduction service no. ED 418 858).
- Crawford, B.A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, 37(9), 916-937.
- Crawford, B.A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, 44(4), 613-642.
- Deboer, G.E. (2004). Historical perspectives on inquiry teaching in schools. In L.B. Flick & N.G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education*. Dordrecht: Kluwer Academic Publishers.
- Ertepinar, H., & Geban, O. (1996). Effect of instruction supplied with the investigative-oriented laboratory approach on achievement in a science course. *Educational Research*, 38, 333-344.
- Geban, O., Askar, P., & Ozkan, I. (1992). Effects of computer simulations and problems solving approaches on high school students. *Journal of Educational Research*, 86, 5-10.

- Gibson, H.L., & Chase, C. (2002). Longitudinal impact of an inquiry-based science program on middle school students' attitudes toward science. *Science Education, 86*(5), 693-705.
- Kennedy, M. (1998). *Form and substance in in-service teacher education*. Arlington, VA: National Science Foundation.
- Krajcik, J.S., Blumenfeld, P., Marx, R.W., & Soloway, E. (2000). Instructional, curricular, and technological supports for inquiry in science classrooms. In J. Minstrell & E.H.v. Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 283–315). Washington, DC: American Association for the Advancement of Science.
- Lederman, N.G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching, 36*(8), 916-929.
- Loucks-Horsley S., Love N., Stiles K.E., Mundry, S., & Hewson P.W. (2003). *Designing Professional Development for Teachers of Science and Mathematics*. 2nd edition. Thousand Oaks, CA: Corwin Press.
- Schwartz, R.S., Lederman, N.G., & Crawford, B.A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88*, 610–645.

CHAPTER 2

A REVIEW OF EMPIRICAL LITERATURE ON INQUIRY PROFESSIONAL DEVELOPMENT: ALIGNMENT WITH BEST PRACTICES AND A CRITIQUE OF THE FINDINGS

Abstract

This review brings together the literature on inquiry-based teaching and learning and science teacher professional development (PD). We present a targeted critical review of research focused specifically on the nature of PD programs purported to emphasize inquiry. Our review analyzes the features of each program and critiques the reported outcomes of each study. Findings from this review suggest a general alignment with recommended features of effective PD as outlined in the literature with a few notable exceptions, including: supporting teachers in developing inquiry-based lesson plans, providing authentic inquiry experiences, and focusing on science content for teachers. More importantly, our review reveals that no reported study has connected participation in inquiry-based PD with all the desired outcomes of teacher PD: enhanced teacher knowledge, change in beliefs and practice, and enhanced student achievement. Implications for future research on inquiry-based PD programs are discussed.

Over a decade ago science education reform documents in the United States advocated changing science teaching in precollege science classrooms from having less emphasis on using direct instruction to a greater emphasis on inquiry-based instruction (American Association for the Advancement of Science [AAAS], 1989, 1993; National Research Council [NRC] 1996, 2000; National Science Teachers' Association Position-Statement, 1998). Although science education reform efforts highlight the importance of inquiry-based instruction, it appears that little has changed regarding how science is taught in the majority of US classrooms. Most teachers do not routinely use inquiry-based instruction in their teaching due to a number of issues including: perceived time constraints due to high-stakes testing; unfamiliarity with how science is practiced (Deboer, 2004); inadequate preparation in science (Krajcik, Mamlok, & Hug, 2000), or they simply do not understand what inquiry is. This problem is more apparent at the elementary and middle school levels, where teachers often have little or no formal science training and lack familiarity with the fundamentals of scientific inquiry and inquiry-based instruction (Kennedy, 1998; Loucks-Horsley, Hewson, Love, & Stiles, 1998, 2003). Inquiry-based teaching is a complex and sophisticated way of teaching that demands significant professional development [PD] (Crawford, 2000, 2007). It appears that the key to change is in providing innovative science teacher education for both preservice and inservice teachers. Unless teachers are supported in developing an understanding of science subject matter, the nature of scientific inquiry, and how to create an inquiry-based learning environment in the classroom, it is unlikely there will be significant shifts in

teacher practice. Thus, a major challenge in the field of science teacher education is to assist teachers in understanding how to enact inquiry-based instruction in their classrooms.

Teacher PD is a well-recognized way to support practicing teachers in carrying out inquiry-based instruction in science classrooms (Loucks-Horsley et al., 1998, 2003; NRC, 1996). PD is regarded as a cornerstone for the implementation of standards-based reform (Committee on Science and Mathematics Teacher Preparation, 2001). Recently, many PD programs have emerged to support classroom teachers in changing their instructional approach to be more consistent with inquiry-based instruction. Millions of dollars have been spent on these programs; however, there is a paucity of empirical evidence supporting the effectiveness of teacher PD in this area (Borko, 2004; Smylie, 1996; Wilson & Berne, 1999). An exhaustive search of the literature revealed that for the most part, only general reviews have been published on science teacher PD (e.g. Hewson, 2007; Kennedy, 1998). Additionally, there has been no targeted review of PD programs focused specifically on scientific inquiry.

The purpose of this paper is to critically review and evaluate those empirical studies pertaining to scientific inquiry PD interventions. Specifically, we are interested in the nature of inquiry-focused PD programs, if and how these programs support teachers in enhancing their knowledge, changing their beliefs and practices, and if these changes can be linked to enhanced student achievement. Our research questions are:

- 1) To what extent are the programs aligned with critical features of effective PD as outlined in this review?

- 2) How robust are the findings of each of these studies?
- 3) What do these findings tell us about PD aimed at promoting inquiry-based instruction in science classrooms?

We begin the review with a background section where we define the terms scientific inquiry, inquiry-based learning and teaching, and discuss where the confusion regarding inquiry arises. Then, we discuss the theoretical underpinnings for teaching science as inquiry and illustrate why inquiry-based instruction is considered an important part of school science. Next, we define teacher PD and discuss the overall goals and best practices for PD as defined by experts in the field, empirical studies, and the *National Science Education Standards* (NSES [NRC, 1996]). In the methods section we present the criteria for our literature review; describe the process of searching for, selecting, and grouping articles, and our analysis scheme. We then present our critical review of the literature, followed by a discussion of findings and implications for promoting effective PD for scientific inquiry.

Background: Scientific Inquiry and Professional Development

Scientific Inquiry: Definitions & Theoretical Underpinnings

There is much confusion among science teachers over the meaning of the term inquiry. Inquiry has been referred to as an elastic term that can be “stretched and twisted to fit people’s differing world views” (Wheeler, 2000, p. 14). The confusion over the meaning of inquiry may arise because nearly every academic discipline has its own definition of the process of inquiry. Throughout their careers most teachers have encountered the word inquiry in a variety of contexts, including college classes,

textbooks, and PD. However, if they have not had personal experience engaging in scientific inquiry they may conflate it with other meanings of the word. Limited experience with scientific inquiry has caused many to equate inquiry with similar teaching techniques, such as hands-on learning, learning by doing, problem based learning or a variety of other methods that do not necessarily guarantee meaningful inquiry is occurring (AAAS, 1993; NRC, 1996).

Some of the confusion may also exist because science education literature and reform documents address inquiry in several different contexts, including scientific inquiry, inquiry-based learning, and inquiry-based teaching. Each of these terms has a particular meaning that when not specified may lead to misunderstandings. Here, we define each term and its relationship to science education. Scientific inquiry has been defined as, "...the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work" (NRC, 1996, p. 23), "the process by which scientific knowledge is developed" (Lederman, 2004, p. 308), or more simply as the research carried out by actual scientists (Chinn & Malhotra, 2002). It has been argued that classroom inquiry will never reach the level of sophistication involved in authentic scientific inquiry, and by presenting classroom inquiry as equal to scientific inquiry, one skews the image of the authentic practice (Lave & Wenger, 1991). Although authentic scientific inquiry differs from classroom inquiry, classroom inquiry can be modeled after the authentic practice of science to enhance student interest and motivation (Crawford, 2000).

The NSES consider classroom inquiry to have three different meanings; two of which are educational outcomes while the third is a teaching strategy. The educational

outcomes of inquiry are composed of one's ability *to do* scientific inquiry, which includes asking and identifying questions, planning and designing experiments, using data, and connecting it with explanations; and inquiry as a content area of study or the *knowledge of how scientists do their work*, for example realizing that scientists ask questions, perform different types of investigations, and produce explanations based on observations (NRC 1996, p. 121). The third meaning of classroom inquiry is a *kind of pedagogy*; inquiry-based teaching concerns the pedagogy of inquiry or one's ability to employ inquiry instruction in the classroom (NRC, 2000). Though it is not the only way to effectively teach science, inquiry-based instruction is thought to have a powerful influence on students' science learning, because it exposes them to a type of learning that parallels the work of practicing scientists (NRC, 1996, 2000).

It is important to note that there are different views of what constitutes inquiry-based instruction. Abrams, Southerland, and Silva (2008) argue that classroom inquiry is multifaceted and difficult to define, and that outcomes are difficult to compare since there are different versions. Many textbooks, unfortunately, promote an incorrect view of scientific inquiry, as proceeding in a prescribed, step-by-step fashion (Bybee, 2004). Thus, science teachers dependent on textbooks may adopt this similar view in their teaching practice. Laboratory investigations that are tightly structured may resemble confirmatory exercises, rather than inquiry. Historically, Schwab (1962) identified two aspects of the nature of scientific inquiry, one in which problems are addressed using scientific principles ("stable enquiry") and another in which principles are questioned ("fluid enquiry"). This translates to students doing science, as well as learning about the ways in which scientific inquiry is carried out. In this view, teachers

create opportunities for their students to learn inquiry skills and to reflect on inquiry. This view of inquiry is echoed in the NSES. The standards add that teaching science as inquiry also targets students learning scientific ideas and the nature of scientific work (NRC, 1996). There are voices critical of the NSES view on inquiry. For example, some suggest reform documents take too narrow of a view of inquiry and scientific literacy, leaving school science unchanged (e.g. Eisenhart, Finkel, & Marion, 1996). Others have questioned the effectiveness of instructional approaches like inquiry, based on the way humans learn and by citing evidence from empirical studies (Kirschner, Sweller, & Clark, 2006). Given this discussion of the varied ideas of inquiry-based teaching, it is not the purpose of this review of inquiry-based PD studies to present a detailed history of inquiry-based teaching or arrive at a conclusion as to the effectiveness of inquiry as an instructional approach. For further clarification of historical and contextual perspectives of inquiry and the effectiveness of inquiry, the authors refer the reader to Deboer (2004) and Anderson (2002) and Kirschner et al. (2006). For the purpose of this paper we use the NSES five essential features of classroom inquiry (NRC, 2000) as a framework for discussing inquiry-based instruction (see Table 2.1).

Theoretical Underpinnings & the Importance of Inquiry Instruction

Constructivism in science education centers on the idea that learners should be engaged in answering authentic scientific questions relevant to their lives (Brown et al., 1989; Dewey, 1938; Schwab, 1976). Reform-based teaching approaches—including inquiry—draw on constructivist views of learning (e.g. Driver, Asoko, Leach, Mortimer, & Scott, 1994). Inquiry-based science teaching focuses on active

Table 2.1

Five essential features of inquiry (NRC, 2000)

NSES, 5 Essential Features of Classroom Inquiry
1) Learner is involved in a scientifically oriented question
2) Learner gives priority to evidence in responding to the question
3) Learner uses evidence to develop an explanation
4) Learner connects explanation to scientific knowledge
5) Learner communicates and justifies the explanation

student knowledge construction in place of merely drill and practice and the memorization of facts. Teaching science as inquiry has the potential to be more relevant to students than other forms of science instruction, like lecture or cookbook labs, because it engages students in negotiating their own understandings with science and approximates how science is practiced (Dewey, 1938). Dewey's perspective on science education focused on solving real world problems based in children's experiences. He argued for an inquiry-based, student-centered education where the role of the teacher was to guide and support students in an active quest for knowledge (Dewey, 1938).

Yet, most teachers do not use inquiry-based instruction in their science classrooms (Stake & Easley, 1978; Wee, Shepardson, Fast, & Harbor, 2007; Wells, 1995; Windschitl, 2002). Preservice teachers are apprentices during their K-16 years of classroom experiences (Britzman, 1991; Lortie, 1975). Thus, many teachers use primarily direct instruction, because it reflects how they were taught. Direct instruction is teacher-centered and focuses on memorizing content and may have little relevance to the learner (AAAS, 1993). Inquiry-based instruction has potential to improve both student understanding of science and engagement in science (AAAS, 1989, 1993; NRC, 1996). Further, inquiry-based science teaching has possibilities of engaging *all* students, including those from underrepresented populations in science, in understanding and becoming motivated to learn science.

Definitions & Characteristics of Effective PD

PD in teaching has been defined as the “sum total of formal and informal learning experiences throughout one's career from preservice teacher education to

retirement” (Fullan, 1991, p. 326). Characteristics of effective PD have been described by well recognized experts in the field of general education (e.g. Darling-Hammond & McLaughlin, 1995; Desimone, 2009) and more specifically in science education (e.g. Loucks-Horsley et al., 1998, 2003). Samples of these characteristics are listed in Table 2.2. Common features of each include engaging participants in inquiry-based learning and modeling teaching strategies, connecting PD to classroom work, and continuity.

Large scale surveys have also aimed to determine factors that contribute towards making science PD effective (Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Garet et al. (2001) conducted a national probability study of 1,027 teachers and reported six characteristics of effective mathematics and science PD programs on teacher learning, including structural features and core features of the programs. Penuel et al. (2007) surveyed 454 teachers to determine characteristics of PD that affect teacher knowledge and curriculum implementation (see Table 2.3 for a list of characteristics of effective PD). Several of the features determined in these studies confirm characteristics of effective PD described in the general education literature; particularly, engaging participants in inquiry-based learning and modeling teaching strategies, connecting PD to classroom work, supporting continued PD, collective participation, and allowing adequate time for PD activities. Additionally, these studies suggest other important characteristics of PD for science teachers, such as focusing on science content knowledge and the importance of discussing how to integrate activities in the classroom.

Reform documents such as the NSES also provide guidelines for PD. The NSES suggest that PD programs in science, “explicitly attend to inquiry—both as a

Table 2.2

Characteristics of Effective Professional Development Described by Darling-Hammond et al. (1995) and Loucks-Horsley et al. (1998).

Darling-Hammond et al. (1995)	Loucks-Horsley et al. (1998)
<ul style="list-style-type: none"> • Engages teachers in concrete tasks of teaching, assessment, observation, and reflection • Engages participants in inquiry, reflection, and experimentation. • Promotes a collaboration between participants and professional developers • Connects to or is coherent with classroom work • Sustains and continues support • Connects to other aspects of school change 	<ul style="list-style-type: none"> • Emphasizes inquiry-based learning, investigations, and problem solving • Helps build pedagogical skills and content knowledge • Models the strategies teachers will use with their students • Builds learning communities where continued learning is valued • Supports teachers in leadership roles • Links to the educational system (district initiatives, state curriculum, etc..) • Changes to insure positive impact

Table 2.3

Characteristics of effective professional development reported by Garet et al. (2001) and Penuel et al. (2007)

Garet et al. (2001)	Penuel et al. (2007)
<ul style="list-style-type: none"> • Focuses on content knowledge • Provides opportunities for active learning • Connects to or is coherent with other activities • Engages teachers in reform-based PD • Promotes collective participation of teachers • Provides an adequate amount of time 	<ul style="list-style-type: none"> • Discusses alignment with local, state, and national standards • Engages teachers in aligning activities with standards • Emphasizes content of particular curriculum during PD • Provides ongoing, coherent PD • Connects to reform-based practices

learning outcome for teachers and as a way for teachers to learn science subject matter” (NRC, 2000, p. 112). Furthermore, the standards call for PD programs to help teachers learn how to teach through inquiry. Our operational definition of *inquiry-based science (IBS) PD* is the following: IBS teacher PD is one that consists of activities that support teachers in creating classroom environments in which students learn science concepts and principles through inquiry, as well as learn about what science is, and how scientists work. In particular, in this type of PD, a teacher would learn how to support students in designing and carrying out scientific investigations, finding solutions to real world problems through asking and revising questions, gathering and analyzing data, using data as evidence in creating explanations, drawing conclusions, and reporting and justifying findings (i.e. Krajcik, Blumenfeld,, Marx, & Soloway, 2000; NRC, 2000).

Method

Selection of Studies for Review

As stated in the introduction, the purpose of this article is to evaluate empirical studies pertaining to scientific inquiry PD interventions. The review was guided by the literature on inquiry and professional development. In selecting the articles, a keyword search using the terms “science inquiry” and “professional development” was conducted in the Educational Resources Information Center (68 results), and Wiley InterScience (289 results) databases. A subsequent search was performed in data bases of four science education journals reporting empirical studies of science teacher PD, the *Journal of Research in Science Teaching* (131 results), *Science Education* (99 results), the *International Journal of Science Education* (72 results), and the *Journal*

of Science Teacher Education (176), to ensure appropriate studies were included. These searches located 835 articles. Many of these articles were discarded, because they were not empirical studies pertaining to inquiry PD for science teachers. To further narrow the scope of the review, we selected only empirical studies published subsequent to the NSES and prior to the completion of this study (1997-2008). Although we located articles published prior to the NSES standards, many of these studies came out of the 'new science curricula' of the 1960's and early 1970's. These studies focused on developing curricula and studying how curricula affected student achievement, rather than how teacher learning through PD affected student achievement. Because of this, we made the decision not to include these studies in this review. Several other studies were located in bibliography searches using a snowball sampling technique (Krathwohl, 1998). All articles selected for review came from singular non-aggregate studies where outcome data were reported on teacher knowledge, changes in teacher beliefs or practice, or student achievement. Finally, we acknowledge that there have been many reports submitted to funding agencies (e.g. National Science Foundation reports) as well as conference papers presented on a similar topic; however, we excluded reports and conference papers in favor of empirical studies published in highly-rated peer-reviewed journals of science teacher education. At the end of this process, we selected 22 articles. However, several of the articles came from PD programs that published more than one study. This occurred in five programs. Thus we combined these articles, leaving a total of 17 programs for review. The contexts of the 17 programs varied from large-scale PD programs, with multiple aims, carried out in urban settings, to smaller-scale PD, primarily focused on

engaging teachers in research, conducted in laboratory or field settings. The common denominator was that each of the programs emphasized supporting teachers in learning about inquiry (see APPENDIX at the end of the chapter for a list of the programs reviewed or see abstracts of each article).

Analyses of Studies

In attempting to remain as objective as possible we relied on expert opinion, education research literature, and reform documents previously mentioned to develop our categories for analysis. We created a list of nine common features of effective inquiry PD by comparing information from Tables 2.2 and 2.3, with reform documents, looking for overlapping characteristics and synthesizing these characteristics into a list of common features of effective inquiry PD. The list includes structural features like total time, extended support, and providing teachers with authentic experiences; and core features including coherency with standards, development of lessons, modeling inquiry, reflection, transference, and content knowledge (see A2.1). *Total time* refers to the amount of time allotted for the PD. It was reported in hours or weeks (weeks if the program completed a full, 40-hour work week). *Extended support* indicates programs that persisted over an extended period of time providing sustained support for teachers. Some programs did this by having periodic workshops or classroom visitations throughout the year, while other programs supported teachers remotely. Each of these formats has the potential to create learning communities outside of the initial PD, promoting collective participation between PD participants. *Authentic Experience* refers to PD programs where teachers conducted an inquiry study that was not predefined, that is, teachers were instrumental in defining

and carrying out the research as if they were scientists. *Coherency* refers to PD programs that aligned with local, state, or national standards. *Developed Lessons* denotes programs where teachers learned about inquiry as a teaching strategy by designing inquiry-based lessons for use in their classrooms. Teachers were often asked to bring current lessons and adapt them into inquiry lessons or design an inquiry-based lesson based on content from the PD for classroom use. *Modeled Inquiry* means the program modeled inquiry-based instruction for the teachers during the PD. In most cases teachers engaged in the same inquiry lessons they would later teach their students. These programs offered teachers the opportunity to engage in classroom inquiry, think about how scientists might work, and experience what inquiry-based instruction might look like. *Reflection* refers to programs where teachers were given the explicit opportunity to reflect on their experiences through journaling, discussion groups, or other activities that promoted reflective thought. *Transference* pertains to programs where there was explicit discussion about enacting the curriculum in the classroom. Finally, *Content Knowledge* indicates the PD program focused on science subject matter and content learning for teachers.

Once the studies were selected, we reviewed these articles to answer the aforementioned questions. To determine alignment with the critical features of effective PD the first author carefully read each article looking for evidence that the PD supported teachers with each of the targeted features identified in the literature. Programs were judged on the presence, absence, or quantity of each feature. The second author reviewed the categorization and together we discussed any differences and came to consensus. Finally, we asked a group of four science educators to repeat

our analysis using several articles reviewed for this study to ensure reliability. Their analysis was consistent with our own. To assess the robustness of the four categories of research findings we examined the methods used in the studies to make claims of enhanced teacher knowledge, enhanced teacher practice, change in teacher beliefs, and enhanced student achievement (see A2.1). Robust studies were those that went beyond teacher self-report and used multiple data sources to establish a connection between the PD and the particular finding.

Results & Discussion

Alignment with Critical Features of Effective Professional Development

Total time. One feature reported to have impact on the outcome of PD is the total amount of time of a program (Garet et al., 2001). The inquiry PD studies critiqued in this review typically ranged in length from a week to six weeks; though one program was considerably shorter (see Table A2.1). Although there is no specified amount of time required for effective PD, programs should provide teachers enough time to fully process and address the doubts and misconceptions they have regarding inquiry. Programs that run for a week or more may be an adequate length of time to help teachers understand aspects of inquiry, if inquiry is the primary focus of the program. However, many PD programs serve multiple purposes. For example, two of the programs spent a great deal of time on literacy development for English language learners and other important topics (Lee, Deaktor, Enders, & Lambert, 2008; Lee, Deaktor, Hart, Cuevas, & Enders, 2005; Lee, Hart, Cuevas, & Enders, 2004; Lee, Lewis, Adamson, Maerten-Rivera, & Secada, 2008; Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008) resulting in very little time focused on inquiry (e.g. two-days

of an eight-day program). Partitioning an already brief program may limit the opportunity to fully address doubts and misconceptions teachers may have regarding inquiry.

Extended support. Thirteen of the seventeen programs critiqued provided extended support for teachers after the initial PD session (see A2.1). Extended support is important because it offers teachers a chance to ask questions and interact with professional developers and their colleagues outside of the workshop, and gives teachers the opportunity to receive feedback on new teaching strategies after using them in their classrooms (Garet et al., 2001). There are a variety of ways to support teachers after an initial workshop including, classroom visits, reunions, where teachers and developers physically come back together, and various types of remote support, like chat groups and threaded discussions. Each of these options can provide extended support. Furthermore, remote support may be helpful in creating professional learning communities promoting collective teacher participation. This might be especially important for teachers in smaller districts where there may be just one science teacher or for PD programs drawing on teachers from a variety of geographic areas, because it can create a professional community that would be impossible without the aid of technology. Unfortunately, the shortest program in total time did not appear to provide continued support for teachers (see Table A2.1). It seems that programs with a limited amount of hours could make up for lack of time with increased follow-up support for teachers after they return to their schools. An alternative way to provide continued support would be to break up a stretch of PD sessions into a series of workshops given throughout the year (e.g. Lee et al. programs). It would be important to provide

teachers adequate time to discuss questions and concerns they might have, as well as their experiences in the classroom.

Authentic experience. Only five of the studies critiqued engaged teachers in authentic inquiry—these experiences paralleled the actual work of scientists (see Table A2.1). In one of these programs, a summer research experience for teachers (Westerlund, Garcia, Koke, & Taylor, 2002), the authentic experience varied from teacher to teacher. Only some of the teachers conducted their own investigations; other teachers learned techniques and assisted scientists in answering pre-existing questions. Another program, not included in the five that engaged teachers in authentic inquiry, was nearly added to this list of programs using authentic inquiry; however, in this particular PD program teachers worked in labs helping scientists with small pieces of ongoing investigations instead of teachers conducting their own investigations (Lotter et al., 2006, 2007). The fact that only five studies engaged teachers in authentic inquiry is problematic. Only in these programs were teachers challenged to help design and carry out research. Engagement in authentic experiences, like research, might be difficult for large-scale programs with many teachers. However, if teachers are expected to enact inquiry-based instruction, engagement in authentic inquiry experiences may be a necessary intervention in assisting them in supporting their students in designing and carrying out investigations in school. As stated in the NSES, “inquiry is in part a state of mind, that of inquisitiveness” (NRC, 2000, p. xii), thus teachers need to experience the various aspects of scientific inquiry. Constructivist views of learning and situated cognition advocate learning in specific contexts and allowing adequate time to reflect and draw on past experiences (Brown, Collins, &

Duguid, 1989; Lave & Wenger, 1991). It is predicted that teachers who experience authentic inquiry, similar to that which they will later enact in their classroom, will be better able to translate their experiences and relate concepts to their students (Dubner, Silverstein, Carey, Frechtling, Busch-Johnsen, & Han, 2001).

Coherency. All 17 programs critiqued aligned their workshops with either state or national standards. This finding is noteworthy, because it suggests that professional developers are making efforts to connect their PD activities and goals to those recommended by science education literature and reform documents. Clearly, teachers will be more likely to enact a curriculum or changes in their teaching, if they see it as relevant to their everyday work.

Developed lessons. Less than half of the programs reviewed (7 of 17) required teachers to develop inquiry-based lessons related to the program objectives (see Table A2.1). One program expected teachers to bring in problematic lessons and adapt them to be more consistent with inquiry (Lotter, Harwood, & Bonner, 2006, 2007). This explicit approach helped teachers learn how to develop their own inquiry lessons and allowed them to collaborate with colleagues and with professional developers. Additionally, the fact that these lessons were already part of the teachers' curriculum made this process relevant.

Although many teachers can teach inquiry-based lessons that have been created by professional developers, it is more difficult to develop one's own inquiry-based lesson. Teachers will likely benefit from PD experiences grounded in the same pedagogical principles they will later enact in their own classrooms (Loucks-Horsley et al., 1998, NRC, 1996). Holliday (2004) suggested the need to be explicit about

inquiry. Explicitly supporting teachers in learning how to develop inquiry-based lessons may help sustain inquiry-based teaching beyond the enactment of a specific program's curriculum.

Modeled inquiry. Sixteen of the seventeen programs reviewed modeled inquiry-based instruction in their PD (see Table A2.1). The extent to which these programs modeled inquiry varied. The longer duration programs specifically emphasizing inquiry gave teachers multiple opportunities to engage in inquiry from the perspective of learners, learn about the work of scientists, and discuss aspects of inquiry-based instruction through lessons and or extended inquiry experiences, similar to those they would use in their classrooms. Shorter duration programs that focused on several topics naturally spent less time modeling inquiry. These shorter programs provided practice tasks, often just one or two lessons from a curriculum. As noted earlier, the essential nature of scientific inquiry and inquiry teaching is often misunderstood by teachers (Deboer, 2004). Because of this confusion, modeling inquiry with teachers during PD is important to help them truly understand the essential features of classroom inquiry. Clearly, if teachers are expected to teach using inquiry they will need to work through content matter in this way (McDermott & DeWater, 2000). Programs that offer more opportunity for teachers to experience inquiry, through modeling the lessons they will later teach in their classes and discussing aspects of inquiry-based instruction, will most likely result in teachers enhancing their knowledge of how to engage their students in inquiry-based instruction.

Reflection. Fifteen out of seventeen of the programs critiqued promoted teacher reflection in their PD through discussions or journaling. Literature on teacher professional knowledge points out the value of reflection to bringing about teacher change (Tobin, Briscoe, & Holman, 1990; Tobin & LaMaster, 1995). Experience alone is not always sufficient for enhancing teacher knowledge and promoting teacher change (Loughran, 2002). Programs that provide explicit time for reflection may encourage teachers to be more metacognitive about what they know, how they know it, and what they do. Inquiry PD programs should provide a structure for teachers to reflect on their experiences. Without including explicit reflection as part of PD experiences, it is unlikely that substantial teacher learning or change will occur.

Transference. Fifteen out of seventeen programs reviewed actively supported teachers in discussing how they might transfer PD materials or experiences into their classrooms. Explicit discussion about how one will enact workshop materials or transfer experiences in the classroom is an essential feature of inquiry PD. Contextual factors are important, and the reality is that there is no classroom environment or teacher that is identical. Allowing workshop time for teachers to discuss these differences with colleagues and professional developers will more likely ensure that teachers will feel comfortable enacting the reformed-based curriculum in their classrooms. Additionally, discussions on transference allow teachers to consider how enactment may look in their classroom.

Content knowledge. Eleven of the seventeen programs reviewed in this study focused on specific content knowledge, including teachers' understanding of NOS, inquiry, or science concepts like chemistry and physics. Supporting teachers in

increasing their own content knowledge and the content to be learned by students is an important feature of PD (Garet et al., 2001; Desimone, 2009). Content knowledge is considered important, because obviously, you cannot teach what you do not know, and many teachers lack specific content knowledge teaching skills. If teachers do not develop adequate content knowledge, they will likely be uncomfortable with the material they teach and have difficulties when they attempt to teach the material.

Robustness of the Findings

Inquiry PD programs reported a range of findings, including enhanced teacher knowledge, enhanced teacher practice, change in teacher beliefs, and enhanced student knowledge as a result of the PD intervention (see Table A2.1). Each of the programs critiqued reported on one or more of these outcome categories. Interestingly, none of the programs we reviewed reported outcomes on all four of these categories. This finding is a concern, because it indicates that none of these studies demonstrated a link between enhanced teacher knowledge to change in beliefs, change in practice, and enhanced student knowledge.

The remainder of this section critiques findings from the studies based on the categories of the findings reported by the authors. These categories include: enhanced teacher knowledge, change in teacher beliefs, change in teacher knowledge, and enhanced student knowledge.

Enhanced teacher knowledge. Enhanced teacher knowledge including subject matter knowledge, knowledge of NOS, and inquiry was measured in a variety of ways. Data included instruments resembling tests, interviews, questionnaires, and classroom observations. Eight of the studies reported enhanced teacher knowledge as a

result of the PD (see Table A2.1). Four of these studies used a pre and post instrument similar to a written test to demonstrate an improvement in teacher content knowledge (Basista & Mathews, 2002; Jeanpierre, Oberhauser, & Freeman, 2005; Westerland et al., 2002) or in science process skills (Radford, 1998). Two studies employed open response questionnaires and interviews to document enhanced teacher conceptions of nature of science and inquiry (Akerson & Hanuscin, 2007; Akerson, Hanson, & Cullen, 2007). Another study used pre/post surveys and a mid-program interview to demonstrate enhanced teacher knowledge of inquiry (Shepardson & Harbor, 2004). A final study used interviews to assess teachers' conceptions of inquiry before and after the institute (Lotter et al., 2006, 2007). The methods discussed in each of these studies appeared appropriate and thorough. Two programs reported on teachers' knowledge during their first year of participation in a PD (Lee et al., 2005; Lee, Lewis et al., 2008). However, since they did not have baseline data on teacher knowledge prior to the intervention, the authors made no attempt to make a claim that the intervention was associated with enhanced teacher knowledge. These studies used Likert-style questionnaires to ascertain teachers' perceptions of their own knowledge at the beginning and end of the school year. Additionally, the authors observed each teacher twice during the school year, but there was no baseline data since observations were conducted only after teachers entered the program. Although the findings appear positive, it is difficult to gauge what one's perception of "more knowledgeable" truly means. Teacher self-report has been referred to as a suspect methodology that provides "unconvincing evidence of real gains" (Frechtling, Sharp, Carey, & Vanden-Kieman Westat, 1995, p. 33). Although the Lee et al. (2005) and Lee, Lewis et al. (2008)

studies indeed offer positive results, the findings could have been bolstered by adding a pre and post instrument and/or a semi-structured interview to better assess teachers' knowledge of science content before the intervention. In general, studies that actively assessed teacher understanding before and after the PD intervention or used multiple methods to verify findings appeared more robust.

Change in teacher beliefs. Change in teacher beliefs concerning the importance of inquiry in teaching science and a level of confidence in implementing inquiry were measured using interviews, questionnaires, and classroom observations. Four studies reported on changes in teacher beliefs as a result of the PD. Lee et al. (2004) used a Likert-style questionnaire to show a statistically significant change in response to the importance of inquiry following the PD. However, classroom observations indicated that the change in belief did not affect classroom practice. Conversely, another study that used a questionnaire to report that teachers felt better prepared verified this finding with informal classroom observations and reviewing teacher portfolios (Basista & Mathews, 2002). Johnson (2007) conducted two interviews to document change in teachers' beliefs as a result of the program. A final study examined teacher pedagogical philosophies using pre/post interviews (Luft, 2001). This study indicated that changes in beliefs were more common in new teachers than veteran teachers. Further, the Luft study found that veteran teachers were more likely to change their teaching practice, than newer teachers. These results highlight two things. First, it appears that very few studies systematically assessed teacher beliefs. Second, assessing teacher beliefs is a difficult endeavor. Further, determining change in a teacher's beliefs is not necessarily indicative of a change in

this teacher's practice. Finally, additional research should focus on alternative ways to assess teacher beliefs beyond primarily using teacher self-reports.

Change in teacher practice. Measurements of enhanced teacher practice of inquiry in the classroom or ability to teach using inquiry included both teacher self-report data and classroom observations. Fourteen of the studies reported on the influence on teacher practice (see Table A2.1). Eleven studies used classroom observation to assess enhanced teacher practice of inquiry-based teaching. Three studies employed teacher self-report data as evidence of enhanced practice of inquiry (Jeanpierre et al., 2005; Lee et al., 2004; Young & Lee, 2005). In addition to teacher self-report, both Jeanpierre et al. (2005) and Lee et al. (2004) used classroom observations to confirm teacher self report data. Findings from Lee et al. (2004) conflicted with teacher self-report data indicating a lack of actual change in classroom practice as a result of the intervention, while observations by Jeanpierre et al. (2005) confirmed teacher self report data. Equivocal results from teacher self-report confirms the concern that Fretchling et al. (1995) identified; teacher self-report data alone, may not actually reflect what is happening in the classroom. In order to assess changes in classroom practice it would be useful to conduct pre and post observations of teacher classroom practice. We realize it is not feasible to always collect a large number of pre-observations, in particular, and a limited number of pre and post classroom observations may not accurately represent the day-to-day nature of a teacher's practice; however, these observations can help to serve as a reference point, in addition to lesson plans, interviews, and other data sources, when attempting to characterize a teacher's practice.

Enhanced student knowledge. The extent of enhanced student knowledge including science subject matter knowledge, knowledge of NOS, and inquiry was measured several different ways, including instruments resembling tests, interviews, and teacher perception of student knowledge. Nine of the fifteen studies reported on enhanced student knowledge (see Table A2.1). Seven of these studies used instruments similar to tests to report gains in student science content knowledge or inquiry skills (Johnson, Kahle, & Fargo, 2007; Lee, Deaktor, et al., 2008 & Lee et al., 2004; Lee, Maerten-Rivera et al., 2008; Marx, Blumenfeld, Krajcik, Fishman, Soloway, Geier, & Tal, 2004; McNeill & Krajcik, 2008; Radford, 1998; Young & Lee, 2005). Two of these studies had design issues that resulted in methodological problems. One group of studies had no control or comparison group (Lee, Deaktor, et al., 2008 & Lee et al., 2004). This made it difficult to ascertain if enhanced student knowledge indeed was the result of the PD program or the result of another factor, such as maturation. A second study only used a post-test (Johnson et al., 2007). Because of this, it was not possible to determine if the teachers' involvement in the PD affected their students' achievement. The remainder of the studies mentioned above appeared to be thorough in measuring growth in student knowledge as a result of the PD. Akerson & Hanuscin (2007) used pre and post interviews to document enhanced student knowledge of NOS. A final study utilized teacher perception to determine enhanced student abilities to develop researchable questions, design and conduct investigations, and share investigation results (Luft, 2001). Findings from this study would have been more robust if researchers had combined teacher self-report with classroom observation.

What do these Findings Tell Us about PD aimed at promoting inquiry-based instruction?

Experts in science education and authors of science reform documents have advocated a focus on inquiry, both as a preferred science teaching approach and as a learning outcome for students. To change the norm in most science classrooms experts have suggested that PD is needed to support teachers' learning about inquiry and teaching science through inquiry. In conducting this review, we were interested in how recent inquiry professional-development programs aligned with features of effective PD and supported teachers in enhancing their content knowledge, changing their beliefs and practices, and the extent to which these changes could be linked to enhanced student knowledge.

Surprisingly, we found very few empirical studies (17) related specifically to science-inquiry professional-development programs actually published in major peer-reviewed journals in science education. However, in those published articles it was promising that the majority of the programs aligned with features of effective PD identified in the literature. Those features infrequently addressed included, a) teachers developing lessons (7/17), b) authentic experiences (5/17), and c) focus on content knowledge (11/17). The literature on teacher PD suggests that each of these features is important in supporting teachers in enacting reform-based practices in their classrooms. Supporting teachers in developing their own inquiry-based lessons and engaging them in authentic research experiences, the two most infrequently addressed features, may likely be the missing link in helping teachers enact inquiry-based

instruction in their own classrooms. Additionally, a focus on science content knowledge will no doubt help teachers feel more comfortable in teaching new topics.

None of the articles reviewed linked enhanced teacher knowledge to changes in teacher beliefs, actual classroom practice, and finally, to enhanced student knowledge. Moreover, the majority of the articles focused on only one or two of these outcomes. An important challenge in education research is to establish a direct relationship between teacher learning and student learning (Blank, de las Alas, & Smith, 2009). Desimone (2009) proposed a conceptual framework for studying and testing the effects of PD on teachers and students. As of yet, no study has made this connection. When made, this connection can be used to either confirm or reject expert opinion regarding inquiry teaching as a preferred instructional practice. Without considering each of these four variables, studies connecting enhanced teacher knowledge to enhanced student knowledge have very little explanatory power (Zeichner, 2005). In exploring the relationships between these variables, researchers must take into account the complexities of classroom teaching. Further, it is important to consider teachers' predispositions to an inquiry-oriented teaching-approach, since many teachers enter PD programs with years of experience in teaching (Kagen 1992). It may also be important to consider the filtering effects of teachers' prior beliefs (Yarrick, Parke, & Nugent 1997) and the idea that changes in teachers' beliefs may lag behind changes in their knowledge and practice (Guskey, 2002). In order to connect growth in teacher knowledge with enhanced student learning researchers need to move beyond, "automatic biases" regarding methods, and employ the most robust and appropriate research methods to answer a particular question (Desimone, 2009). For

instance, certain studies may require surveys or interviews while observations or a combination of methods may be appropriate for other studies. For example, in attempting to access teacher beliefs, a researcher might use a Likert-style questionnaire in order to understand a phenomenon from the teacher's perspective. Teacher self-report can then be followed-up with classroom observations and teacher interviews, in order to confirm teacher self-report.

Conclusions and Implications

From our targeted review, it is apparent that there is a need for more published empirical research on the effectiveness of PD models related to teachers facilitating their students in understanding and using scientific inquiry. Designers of teacher PD programs need to know to what extent teachers' experiences change and enhance teacher practice, and most importantly, enhance student achievement. We found evidence that many studies focused on inquiry PD have been presented at annual science education conferences, yet few have reached the publication stage in prominent science educational research journals, as of this writing. The existing studies, reviewed in this article, report a range of outcomes, including enhanced teacher knowledge, changes in teacher beliefs and practice, and growth in student knowledge; however, to the best of our knowledge, there is no existing study that reports on all of these.

We recommend that future studies be designed to investigate the connections between the design of inquiry-focused PD, teacher knowledge, changes in teacher beliefs and practice, and student knowledge. Although it is acknowledged that there is no one formula for science teacher PD (Loucks-Horsley et al., 1998, 2003), we did

find that the programs reviewed in this study aligned with many of the features of effective PD. However, no single study we reviewed incorporated all the features of effective inquiry-based science PD, as advocated in the literature. Future research studies should attempt to explore which of the nine features of effective PD identified in this paper are most crucial for teacher growth. Experimental or quasi-experimental design might help to elucidate the most important features of effective PD (Wayne, Yoon, Zhu, Cronen, & Garet, 2008).

A limitation of this targeted critical review is that we did not consider the extent of the interactions between various features of effective PD defined in the literature. For instance, is there a relationship between the duration of a program and how scientific inquiry was modeled? This kind of analysis was beyond the scope of our study. We suggest that a future critical literature review might look at the interactions between variables to determine recommendations for the most effective combinations of features in PD programs.

Effective inquiry PD should support teachers in enhancing their knowledge and changing their practice. Teachers who lack science content knowledge or pedagogical knowledge will likely have difficulty teaching science as inquiry. If teachers are expected to change their teaching practice from using mainly a traditional approach to a more inquiry-based approach, they will need to possess a depth of science content knowledge, understand what inquiry is, have experience in both conducting scientific inquiry and teaching using inquiry-based approaches, and, finally, have adequate practice adapting lessons to be congruent with inquiry-based instruction. With this in mind, it would be important to develop an empirically-based Inquiry Teacher Professional Development Framework for science teaching, in like manner as

suggested by Loucks-Horsley et al. (2003). Although researchers have suggested models for supporting teachers in implementing reform-based teaching (e.g. Marx, Blumenfeld, Krajcik, & Soloway, 1997, 1998; Fishman, Marx, Best, & Tal, 2003) these models do not include an authentic inquiry experience as a necessary component. Other models (e.g. Shepardson et al., 2004) have included authentic inquiry experiences, but do not include opportunity for teachers to develop their own inquiry-based lessons. We argue that a framework for effective inquiry PD would provide a structure for challenging teachers to examine their knowledge and beliefs and reflect on their teaching practice, allow teachers the opportunity to experience authentic scientific inquiry in meaningful contexts similar to how they will teach in their classrooms, support teachers in developing their own inquiry-based lessons, and focus on both content knowledge and pedagogical knowledge. Finally, we end with an endorsement of Hilda Borko's AERA presidential address and article (2004) on effective teacher PD, making the point that we have much work to do and many questions to answer about high-quality PD for all teachers, particularly, in the case we pose, related to inquiry-specific PD.

APPENDIX

Table A2.1

Shows alignment with the critical features of professional development and the reported findings of each of the studies reviewed

Study	Goal	Level	Structural Features			Core Features						Research Findings			
			Total Time	Extend Support	Authentic Exp	Coherence	Dev Lesson	Modeled Inquiry	Reflect	Transfer	Content Know	(+)teacher know	Δ belief	Δ practice	(+)student know
1) Lee (2004) JRST & Lee (2005) JRST, & Lee (2008) JRST	TB, Tpr, SA	E	8 days	y	n	y	n	y	y	y	y	n	y	y	y
2) Lee (2008) JRST & Lee (2008) SE	SA, TK, Tpr	E	14 days	y	n	y	n	y	y	y	y	n	n	n	y
3) Marx (2004)	SA	M	1 wk+	y	n	y	n	y	y	y	n	n	n	y	y
4) McNeill (2008)	Tpr, SA	M	1 wk+	y	n	y	n	y	n	y	n	n	n	y	y
5) Young (2005)	SA, Tprep	E	12 hrs +	n	n	y	n	y	n	n	n	n	n	y	y
6) Taitelbaum (2008)	Tpr	S	61 hrs +	y	n	y	n	y	y	y	y	n	n	y	n
7) Luft (2001)	TB, Tpr	M/S	11 days +	y	n	y	y	y	y	n	y	n	y	y	y
8) Lotter (2007) JRST & Lotter (2006) JSTE	TB, Tpr, TK	S	2 wks +	y	n	y	y	y	y	y	y	y	n	y	n
9) Akerson	TK,	E	84	y	n	y	y	y	y	y	y	y	n	y	y

(2007) JRST	TB, Tpr		hrs												
10) Akerson (2007) JSTE	TK	E	2 week s	n	n	y	y	y	y	y	y	y	n	n	n
11) Johnson (2007) JRST & Johnson (2007) JSTE	SA, Tpr, TB	M	198 hrs	y	n	y	y	y	y	y	n	n	y	y	y
12) Basista (2002)	TK, TB	M/S	72 hrs	y	n	y	y	y	y	y	y	y	y	n	n
13) Jeanpierre (2005)	TK, Tpr	S	100 hrs	y	y	y	n	y	y	y	y	y	n	y	n
14) Shepardson (2004)	TK, Tpr	E/S	4 wks	y	y	y	n	y	y	y	y	y	n	y	n
15) Radford (1998)	TK, Tat, SK, Sat	E/S	3 wks+	y	y	y	n	y	y	y	y	y	n	y	y
16) Blanchard (2008)	TK, Tpr	S	6 wks+	n	y	y	y	y	y	y	n	n	n	y	n
17) Westerland (2002)	TK, Tpr	S	8 wks	n	y/n	y	n	n	y	y	n	y	n	y	n

Note. TB = Teacher Beliefs, Tpr = Teacher Practice, SA = Student Attitude, Tprep = Teacher Preparation, TK = Teacher Knowledge, Tat = Teacher Attitude, SK = Student Knowledge, E = Elementary, M = Middle, S = Secondary

Abstracts of programs included in this review

1) Lee et al. (2004) *Journal of Research in Science Teaching (JRST)*- This study reported on the first year of a three year investigation aimed at enhancing elementary teachers' beliefs and practices related to inquiry-based science. Specifically, the authors described the reported views and practices of 53, 3rd and 4th grade teachers in a large urban area (with high ELL population) before and after the intervention. The intervention consisted of four full-day teacher workshops and the design of instructional units. The workshops took place during the school year and focused on inquiry-based science instruction and incorporating English language and literacy, as well as students' home languages, into science instruction. Two, long-term (2-3 months of class time), instructional units were designed at each grade level. The authors used a mixed methods approach including pre-post interviews and questionnaires, as well as classroom observations to describe teachers' beliefs and practices related to inquiry.

Lee et al. (2005) *JRST*- This study investigated the impact of an instructional intervention on 1,523, third and fourth grade students whose teachers participated in a PD program (see above for details on the PD). Specifically, the paper reported on science and literacy achievement as a result of the intervention. The authors used a pre-post instrument to assess students understanding of science concepts and scientific inquiry.

Lee, Deaktor et al. (2008) *JRST*- This study examined the impact of a multiple-year intervention on third, fourth, and fifth grade students' science achievement. The paper reported on two years of science achievement data at each grade level. Teachers participated in two-years of PD (see above for details on year 1). The second year of PD consisted of four full-day teacher workshops. The workshops took place during the school year and had a similar focus as the first year; however, there was an emphasis on sharing experiences from enacting the curriculum. Again, a large focus of the PD was on literacy and supporting English language learners. The authors used a pre-post instrument to assess students understanding of science concepts and scientific inquiry.

2) Lee, Maerten-Rivera, et al. (2008) *JRST*- This study reported on the first year of a five year investigation aimed at supporting 3rd-5th grade students in science and literacy achievement. Specifically, the authors examined students' science achievement at 15 elementary schools in a large urban area (with high ELL population) after their teachers participated in a PD intervention. The intervention included five days of workshops during the school year, focusing on the topics teachers would later enact in their classrooms. Additionally, a series of curriculum units and teachers guides were developed for classroom use. The authors used a 10-question pre-post instrument to assess student gains in science content and science inquiry in comparison to a control or comparison group.

Lee, Lewis et al. (2008) *Science Education (SE)*- This study examined the reported knowledge and practice of 38, third grade teachers as they participated in the first year of a five year PD program (see above for details on the PD). The authors used a teacher self-report questionnaire to obtain information on teacher knowledge of science content, practice in scientific understanding, and practice in scientific inquiry; this was administered to teachers during the final workshop. Classroom observations were conducted twice during the teaching of curricular units (using a scaled instrument), once at the beginning of the year and once at the end of the year to measure teacher knowledge of science content, practice in scientific understanding, and practice in scientific inquiry. Post-observations interviews were employed to gain further information about conceptions of science and inquiry.

3) Marx et al. (2004) *JRST*- This study investigated student learning of science content and process after their teachers participated in a PD program. The program included a summer PD workshop, monthly work sessions, teacher discussion groups, and classroom support. Additionally, a series of curriculum materials were developed to engage students in inquiry-based learning activities. The

authors used a pre-post instrument to assess gains in student science content and process as a result of the intervention.

4) McNeill et al. (2008) JRST- This study examined middle school teachers' instructional practice and student learning after a PD program. The program included a one-week summer PD and curriculum materials. The summer PD provided teachers with generalizable knowledge for teaching curriculum materials. Teachers attended two-day workshops prior to teaching specific units. Curriculum materials were developed to engage students in long term (up to 8 weeks) inquiry-based learning activities. The authors used observation to evaluate teacher practice and a pre-post instrument to measure student learning.

5) Young et al. (2005) Journal of Science Education and Technology- This study compared the performance of 5th grade students whose teachers had PD related to a kit-based inquiry science curriculum to students whose teachers did not. It also reported on teaching practice related to inquiry. The program included six hours of basic training followed by another six hours of follow-up training a year or two after the initial training. Curriculum materials were provided for teachers as part of kits. The authors used a pre-post instrument to assess gains in student science content including nature of science. Additionally, the authors used questionnaires to describe classroom teaching practice.

6) Taitelbaum et al. (2008) International Journal of Science Education (ISJE)- This study looked at the change in high school chemistry teachers' classroom practice as a result of a PD experience. The PD was designed to increase teachers' knowledge and pedagogy so they could support their students in acquiring inquiry skills. The PD consisted of three parts: the development of a teacher's guide to support teachers in teaching through inquiry, a summer induction course which supported teachers in using an inquiry approach, and a series of school year workshop where inexperienced teachers shared their inquiry teaching experiences with their peers. The authors used classroom observations, interviews, teacher portfolios, and documentation of the workshop to report on changes in teaching practice as a result of the PD.

7) Luft (2001) IJSE- This study examined the impact of an in-service PD program on 14 secondary science teachers' beliefs and practices related to inquiry. The PD was designed to support teachers in enacting extended inquiry cycles. The PD consisted of a day workshop during the school year as well as five days over the summer where teachers participated in and developed extended inquiry lessons. Follow-up activities including five, one-day school year meetings were held to discuss concerns and share what teachers were doing in their classrooms. The author used classroom observations to report on teaching practice and a series of standardized pre-post interviews to report on teachers' beliefs.

8) Lotter et al. (2007) JRST- This study described how secondary teachers' conceptions of inquiry and beliefs on teaching changed throughout a PD experience and discussed how changing conceptions related to inquiry teaching practice. The PD program included a two-week summer institute consisting of morning workshops where teachers learned about inquiry-based teaching and afternoon research experience in university laboratories. The summer institute was followed by three additional, three-hour workshops during the academic year where teachers reflected on the implementation of the lessons they designed. The authors used qualitative methods to develop three cases of teacher change. Data included pre-post summer institute interviews, as well as interviews after each academic year workshop to describe teachers' conceptions of inquiry and classroom observations to describe inquiry-based teaching practice for each of the cases.

Lotter et al. (2006) Journal of Science Teacher Education (JSTE)- This study investigated the conceptions of inquiry developed by teachers during the program (see above for details on the PD). Teachers' conceptions of inquiry before and after the institute were assessed using pre-post interview data and through the analysis of teacher designed lessons created during the PD.

9) Ackerson et al. (2007) JRST- This study examined the impact of a three-year PD program on elementary teachers conceptions of NOS and inquiry, their classroom practice, and their student conceptions of NOS and inquiry. The PD program included a series of monthly half-day workshops at the participating elementary school, where teachers engaged in scientific inquiry with explicit NOS

instruction and adapted and revised their current curriculum to be more inquiry-based and teach about NOS. Teachers also received on site support that was specific to each teacher. The authors used pre-post questionnaires and interviews along with field notes from the workshops to construct three cases of teachers' conceptions of NOS and inquiry. Additionally, classroom observations were conducted as a further source of teachers' understandings and teaching practice for each of the cases. Pre-post questionnaires and interviews with students were conducted to determine students' conceptions of NOS and inquiry.

10) Ackerson et al. (2007) JSTE- This study examined the impact of a PD program on 17 elementary teachers' conceptions of NOS. The PD program consisted of a two-week summer workshop where teachers learned about science content through inquiry and received support on teaching about content matter like physics and NOS using an inquiry-based instructional approach. The authors used pre-post surveys to assess participants views on NOS and inquiry. Additionally, a subset of teachers was interviewed before and after the summer institute to validate the authors' interpretations.

11) Johnson et al. (2007) JRST- The first study investigated the relationship between middle school teachers' participation in whole school PD and student achievement in science. Eleven teachers participated in a two-week summer institute at a local university followed by monthly half-day workshops for three years following the initial summer institute. The summer institute consisted of immersion in standards-based instruction and developing or modifying the school's current curriculum. Monthly workshops focused on modifying curriculum and providing support for one another. The authors used a pre-post instrument to compare student achievement of students whose teachers attended the workshops to students of control teachers.

Johnson (2007) JSTE-The second study explored the teachers' implementation of standards-based instruction in the classroom throughout a two-year period (see above for details on the PD). The author used a combination of interviews and classroom observations to develop six cases of instructional change and change in teachers' beliefs.

12) Basista et al. (2002) School Science and Mathematics- This study investigated the impact of a science and math PD on upper elementary and secondary teachers' content understanding and pedagogical knowledge in order to promote standards based teaching in the classroom. Twenty-two teachers participated in a four-week summer institute meeting eight hours a day, for three days a week. The institute focused on both content and pedagogy and engaged teachers in inquiry-based learning environments. Teachers also received support during the academic year. The authors used a pre-post instrument to assess gains in teacher content knowledge and a Likert-style survey to determine classroom implementation. Informal classroom observations were used and materials collected to check for consistency with the survey results.

13) Jeanpierre et al. (2005) JRST- This study examined the impact of a PD program on teachers' content knowledge and teaching practice. Forty-four teachers participated in a PD program consisting of a two-part resident institute including a week in the summer and a week in the fall. Teachers participated in inquiry activities, learned science content, and conducted short, inquiry-based research projects. Additionally, teachers participated in an ongoing scientific study and brought this investigation to their schools. The authors used a pre-post instrument to determine gains in content knowledge. Changes in classroom teaching practice were determined using a pre-post survey to assess the current use of inquiry, classroom observations after the two-part institute, teacher interviews, and member checking.

14) Shepardson et al. (2004) Environmental Education Research- This study examined the impact of a PD program on teachers' knowledge of inquiry and classroom practice. The PD program was divided into two groups. The first group of 30 elementary and secondary teachers participated in a four-week summer institute designed to enhance teachers' inquiry-based teaching, content knowledge, and inquiry abilities. Teachers participated in investigations and later designed their own research project which they later presented to the group. All along teachers discussed how their work related to inquiry described by the NSES. These teachers later provided PD for the second group of 31 teachers at their

individual schools. The authors used observations of classroom practice, pre-post lesson profiles, a pre-post open response survey, and interviews to make claims about knowledge of inquiry and changes in classroom practice as a result of the PD.

15) Radford (1998) JRST- This study examined the impact of a PD program on upper elementary through high school teachers' science content knowledge, process skills, and attitudes towards teaching science, as well as on their students' process skills and attitudes toward science. The PD program ran for three years; each year 30 teachers participated. It included a three-week summer course at a university, consisting of lab and field work, where teachers participated in inquiry and talked about inquiry-based teaching; a four-week independent science investigation; and follow-up workshops during the academic year. The author used pre-post instruments to assess teachers' gains in science content and process skills and a Likert-style survey to measure teachers' attitudes towards science. Teachers were also asked to keep portfolios during their teaching of the lessons. A pre-post instrument was given to students and comparison students to report on gains in process skills. A similar Likert-style survey was also given to students to measure their attitudes towards science.

16) Blanchard (2008) SE- This study examined the link between a research experience for teachers PD program, and secondary teachers' conceptions of inquiry and use of inquiry in the classroom. The PD consisted of a six-week resident institute at a biological field station designed to support teachers in learning about inquiry as a method for scientific research and a teaching strategy. Twenty-four teachers participated in the program. The program challenged teachers to develop a scientific question, a method to research the question, and conduct the study. Additionally, teachers developed a lesson using the inquiry model the learned during the program. The author used a pre-post questionnaire and interview to measure teachers' conceptions of inquiry. Inquiry enactment was assessed through pre-post classroom observations and interviews. Through these, the author developed four cases of teacher change.

17) Westerland et al. (2002) JSTE- This study was carried out in the second-year of a five-year grant. The particular study examined the effects of a PD experience on teachers' content knowledge and classroom practice. Twenty-three secondary science teachers were placed in an eight-week summer research experience with laboratory scientists at a university. Participants' experiences varied due to their placement, but most reports suggested that teachers engaged in authentic research. Additionally, teachers kept journal reflections of their work and related it to classroom teaching. The authors used pre-post content knowledge assessments, developed by cooperating scientists to assess gains in knowledge and conducted classroom observations and interviews with four teachers to look for evidence of teachers applying what they learned in their classrooms.

References

- Abrams E.D., Southerland S.A., Evans C.A. (2008). Inquiry in the classroom: Identifying necessary components of a useful definition. In: Abrams ED, Southerland S.A. (Eds.), *Integrating inquiry in the science classroom: realities and opportunities*. Information Age Publishing, Greenwich, CT, pp x–xiii, 265.
- Crawford, B.A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, 37(9), 916-937.
- Crawford, B.A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, 44(4), 613-642.
- Akerson, V.L., & Hanuscin, D.L. (2007). Teaching nature of science through inquiry: Results of a 3-year professional development program. *Journal of Research in Science Teaching*, 44(5), 653-680.
- Akerson, V.L., Hanson, D.L., & Cullen, T.A. (2007). The influence of guided inquiry and explicit instruction on K-6 teachers' views of nature of science. *Journal of Science Teacher Education*, 18, 751-772.
- American Association for the Advancement of Sciences. (1989). *Project 2061: Science for all Americans*. New York: Oxford University Press.
- American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.
- Basista, B., & Mathews, S. (2002). Integrated science and mathematics professional development programs. *School Science and Mathematics*, 102(7), 359-370.

- Blanchard, M.R., Southerland, S.A., & Granger, E.M. (2009). No silver bullet for inquiry: Making sense of teacher change following an inquiry-based research experience for teachers. *Journal of Research in Science Teaching*, 93(2), 322-360.
- Blank, R.K, de las Alas, N., & Smth, C. (2008). Does teacher professional development have effects on teaching and learning? Analysis of evaluation finding from programs for mathematics and science teachers in 14 states. Washington, DC: Council of Chief State.
- Borko, H. (2004). Professional development and teacher learning: Mapping the terrain *Educational Researcher*, November 2004; 33: 3 - 15.
- Britzman, D. (1991). *Practice makes practice: A critical study of learning to teach*. Albany: State University of New York press.
- Brown, J.S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, 18(1), 32-42.
- Bybee, R.W. (2004). Scientific inquiry and science teaching. In L.B. Flick & N.G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education*. Dordrecht: Kluwer Academic Publishers.
- Chinn, C.A., & Malhotra, B.A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, 86, 175-218.
- Committee on Science and Mathematics Teacher Preparation. (2001). *Educating*

teachers of science, mathematics, and technology: New practices for the new millennium. Washington, DC: National Academy Press.

Darling-Hammond, L., & McLaughlin, M.W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan*, 76(8), 597.

Deboer, G.E. (2004). Historical perspectives on inquiry teaching in schools. In L.B. Flick & N.G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education.* Dordrecht: Kluwer Academic Publishers.

Desimone, L.M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, 38(3), 181-199.

Dewey, J. (1938). *Experience and education.* New York: Collier Books.

Dubner, J., Silverstein, S.C., Carey, N., Frechtling, J., Busch-Johnsen, T., & Han, J. (2001). Evaluating science research experience for teachers programs and their effects on student interest and academic performance: A preliminary report on an ongoing collaborative study by eight programs. Paper presented at the Materials Research Society Symposium Proceedings.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23(7), 5-12.

Eisenhart, M., Finkel, E., & Marion, S.F. (1996). Creating the conditions for scientific literacy: A re-examination. *American Educational Research Journal*, 33(2), 261-295.

- Fishman, B.J., Marx, R.W., Best, S., & Tal, R.T. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education*, 19(6), 643-658.
- Frechtling, J.A., Sharp, L., Carey, N., & Vanden-Kieman Westat, N. (1995). *Teacher enhancement programs: A perspective on the last four decades*. Washington, DC: National Science Foundation.
- Fullan, M., with Steigelbauer, S. (1991). *The new meaning of educational change* (2nd ed.). New York: Teachers College Press.
- Garet, M.S., Porter, A.C., Desimone, L., Birman, B.F., & Yoon, K.S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, 38(4), 915-945.
- Guskey, T.T. (2002). Professional development and teacher change. *Teachers and Teaching: Theory and Practice*, 8(3/4), 381-391.
- Hewson, P.W. (2007). Teacher professional development in science. In S.K. Abell & N.G. Lederman (Eds.), *Handbook of Research on Science Education*. Mahwah: Lawrence Earlbaum Associates.
- Holliday, W.G. (2004). A balanced approach to science inquiry teaching. In L.B. Flick & N.G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education*. Dordrecht: Kluwer Academic Publishers.
- Jeanpierre, B., Oberhauser, K., & Freeman, C. (2005). Characteristics of professional development that effect change in secondary science teachers' classroom practices. *Journal of Research in Science Teaching*, 42(6), 668-690.

- Johnson, C.C., Kahle, J.B., & Fargo, J.D. (2007). A study of the effect of sustained, whole-school professional development on student achievement in science. *Journal of Research in Science Teaching*, 44(6), 775-786.
- Johnson, C.C. (2007). Whole-school collaborative sustained professional development and science teacher change: Songs of progress. *Journal of Science Teacher Education*, 18, 629-661.
- Kagen, D.M. (1992). Professional growth among preservice and beginning teachers. *Review of Educational Research*, 62, 129-169.
- Kennedy, M. (1998). *Form and substance in in-service teacher education*. Arlington, VA: National Science Foundation.
- Kirschner, P.A., Sweller, J., Clark, R.E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41(2), 75-86.
- Krajcik, J.S., Blumenfeld, P., Marx, R.W., & Soloway, E. (2000). Instructional, curricular, and technological supports for inquiry in science classrooms. In J. Minstrell & E.H.v. Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 283–315). Washington, DC: American Association for the Advancement of Science.
- Krajcik, J.S., Mamlok, R., & Hug, B. (2000). Modern content and the enterprise of science: Science education in the twentieth century. In L. Como (Ed.), *Education across a century: The centennial volume. One-hundredth yearbook*

of the national society for the study of education. Chicago: University of Chicago Press.

Krathwohl, D.R. (1998). *Methods of educational and social science research: An integrated approach*. Reading, MA Addison Wesley Longman, Inc.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Lee, O., Deaktor, R., Enders, C., & Lambert, J. (2008). Impact of a multiyear professional development intervention on science achievement of culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching*, 45(6), 726-747.

Lee, O., Deaktor, R.A., Hart, J.E., Cuevas, P., & Enders, C. (2005). An instructional intervention's impact on the science and literacy achievement of culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching*, 42(8), 857-887.

Lee, O., Hart, J.E., Cuevas, P., & Enders, C. (2004). Professional development in inquiry-based science for elementary teachers of diverse student groups. *Journal of Research in Science Teaching*, 41(10), 1021-1043.

Lee, O., Lewis, S., Adamson, K., Maerten-Rivera, J., & Secada, W.G. (2008). Urban elementary school teachers' knowledge and practices in teaching science to English language learners. *Science Education*, 92(4), 733-758.

Lee, O., Maerten-Rivera, J., Penfield, R.D., LeRoy, K., & Secada, W.G. (2008). Science achievement of English language learners in urban elementary

- schools: Results of a first-year professional development intervention. *Journal of Research in Science Teaching*, 45(1), 31-52.
- Lortie, D. (1975). *Schoolteacher: A sociological study*. Chicago: University of Chicago Press.
- Lotter, C., Harwood, W.S., & Bonner, J. J. (2007). The influence of core teaching conceptions on teachers' use of inquiry teaching practices. *Journal of Research in Science Teaching*, 44(9), 1318-1347.
- Lotter, C., Harwood, W.S., & Bonner, J.J. (2006). Overcoming a learning bottleneck: Inquiry professional development for secondary science teachers. *Journal of Science Teacher Education*, 17, 185-216.
- Loucks-Horsley, S., Hewson, P.W., Love, N., & Stiles, K.E. (1998). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin Press.
- Loucks-Horsley S., Love N., Stiles K.E., Mundry, S., & Hewson P.W. (2003). *Designing Professional Development for Teachers of Science and Mathematics*. 2nd edition. Thousand Oaks, CA: Corwin Press.
- Loughran, J.J. (2002). Effective reflective practice. *Journal of Teacher Education*, 53(1), 33-43.
- Luft, J.A. (2001). Changing inquiry practices and beliefs: the impact of an inquiry-based professional development programme on beginning and experienced secondary science teachers. *International Journal of Science Education*, 23(5), 517-534.

- Marx, R.W., Blumenfeld, P., Krajcik, J.S., & Soloway, E. (1997). Enacting project-based science: Challenges for practice and policy. *The Elementary School Journal*, 97(4), 341-358.
- Marx, R.W., Blumenfeld, P., Krajcik, J.S., & Soloway, E. (1998). New technologies for teacher professional development. *Teaching and Teacher Education*, 14, 33-52.
- Marx, R.W., Blumenfeld, P.C., Krajcik, J.S., Fishman, B., Soloway, E., Geier, R., Tal, R.T. (2004). Inquiry-based science in the middle grades: Assessment of learning in urban systemic reform. *Journal of Research in Science Teaching*, 41(10), 1063-1080.
- McDermott, L.C., & DeWater, L.S. (2000). In J. Minstrell & E.H. v. Zee (Eds.), *Inquiring into inquiry learning and teaching in science*. Washington, DC: National Academy Press.
- McNeill, K.L., & Krajcik, J. (2008). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching*, 45(1), 53-78.
- National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.
- National Research Council. (2000). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.
- National Science Teachers Association. (1998). *The National Science Education Standards: A Vision for the Improvement of Science Teaching and Learning*. Arlington, VA: NSTA.

- Penuel, W.R., Fishman, B.J., Yamaguchi, R., & Gallagher, L.P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, 44(4), 921-958.
- Radford, D.L. (1998). Transferring theory into practice: A model for professional development for science education reform. *Journal of Research in Science Teaching*, 35(1), 73-88.
- Schwab, J.J. (1976). Education and the state: Learning community. In *The great ideas today*. Chicago: Encyclopedia Britannica.
- Shepardson, D.P., & Harbor, J. (2004). ENVISION: the effectiveness of a dual-level professional development model for changing teacher practice. *Environmental Education Research*, 10(4), 471 - 492.
- Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4-14.
- Shulman, L.S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1-22.
- Smylie, M.A. (1996). From bureaucratic control to building human capital: The importance of teacher learning in education reform. *Educational Researcher*, 25(9), 9-11.
- Stake, R., & Easley, J. (1978). *Case studies in science education*. Urbana, IL: The University of Illinois.
- Taitelbaum, D., Mamlok-Naaman, R., Carmeli, M., & Hofstein, A. (2008). Evidence for teachers' change while participating in a continuous professional development programme and implementing the inquiry approach in the

- chemistry laboratory. *International Journal of Science Education*, 30(5), 593-617.
- Tobin, K., Briscoe, C., & Holman, J.R. (1990). Overcoming constraints to effective elementary science teaching. *Science Education*, 74(4), 409-420.
- Tobin, K., & LaMaster, S.U. (1995). Relationships between metaphors, beliefs, and actions in a context of science curriculum change. *Science Education*, 32(3), 225-242.
- Wayne, A.J., Yoon, K.S., Zhu, P., Cronen, S., & Garet, M.S. (2008). Experimenting with teacher professional development: Motives and methods. *Educational Researcher*, 37(8), 469-479.
- Wee, B., Shepardson, D.P., Fast, J., & Harbor, J. (2007). Teaching and learning about inquiry: Insights and challenges in professional development *Journal of Science Teacher Education*, 18(1), 63-89.
- Wells, G. (1995). Language and the Inquiry-Oriented Curriculum. *Curriculum Inquiry*, 25(3), 233-269.
- Westerlund, J.F., Garcia, D.M., Koke, J.R., Taylor, T.A., & Mason, D.S. (2002). Summer scientific research for teachers: The experience and its effect. *Journal of Science Teacher Education*, 13(1), 63-83.
- Wheeler, G. F. (2000). The Three Faces of Inquiry. In J. Minstrell & E.H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science*. Washington, D.C.: National Academy Press.

- Wilson, S.M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. *Review of Research in Education*, 24, 173-209.
- Windschitl, M. (2002). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education*, 87(1), 112-143.
- Yarrick, R., Parke, H., & Nugent, J. (1997). Struggling to report deeply rooted change: The "filtering effects" on teachers' beliefs on understanding transformation views of teaching science. *Science Education*, 81(2), 137-159.
- Young, B., & Lee, S. (2005). The effects of a kit-based science curriculum and intensive science professional development on elementary student science achievement. *Journal of Science Education and Technology*, 14(5), 471-481.
- Zeichner, K.M. (2005) A research agenda for teacher education. In M. Cochran-Smith & K.M. Zeichner (Eds). *Studying teacher education: The report of the AERA panel on research and teacher education*. Washington, DC: Lawrence Earlbaum Associates.

CHAPTER 3

INQUIRY-BASED INSTRUCTION IN SCIENCE CLASSROOMS: IS IT HAPPENING?

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 provide evidence-based 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 5th-9th grade teachers before their participation and engagement in an inquiry-based professional development (PD) program. We used a range of data sources, including program applications, classroom observations, videotape data, an open-response questionnaire, and semi-structured interviews to assess the teaching practice and views of inquiry and NOS of the teachers before they participated in the program. We also looked for relationships between teachers' pre-program 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* or *important*

understandings about inquiry. This study provides empirical evidence for the claim that even some of the better prepared teachers currently struggle to enact reformed-based teaching. Further, this study highlights the critical need for an agreed upon definition of inquiry-based instruction, better measures for inquiry and NOS, and rigorous PD to support teachers in learning about inquiry and NOS and enacting reform-based instruction in their classrooms.

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). A recent synthesis of the literature by Minner, Levy, and Century (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, Lederman, & Crawford, 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 [PD] (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 (Stake & Easley, 1978), classroom observations of science and mathematics teachers from the Looking 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 before their involvement in an inquiry-based PD 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' pre-program views of inquiry and NOS and their teaching practice?

A series of related studies examine the impact of the PD experience on teacher knowledge and classroom teaching practice after the PD.

Theoretical Framework

Teaching Science as Inquiry and about NOS

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. 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. 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 Table 3.1 for a list of the *understandings, abilities, and essential features of inquiry* and Table 3.2 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 inquiries 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 agreement of 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.

Teaching Knowledge

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 and NOS, 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 PD program, Pilot Groups 1 & 2 (P1 & P2). All 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 before they participated in the PD 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 questionnaire of views on inquiry and NOS. Additionally we conducted interviews with a subset of the participants.

Context of Study

This study took place during the initial stages of a teacher PD program focused on inquiry and NOS. More than 120, 5th-9th grade teachers to the program. A total of 30 teachers were selected to participate in the program. Selection criteria included: quantity of college science courses taken, presence or absence of science research experience, teaching experience (years), quantity of science PD, what they hoped to

gain, their willingness to participate in 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, had taken nearly 12 college-level science courses, and reported having more than three PD experiences in science. Moreover, most of the 7th-9th grade teachers were teaching in their accredited field. We suggest these teachers are perhaps some of the better prepared and motivated teachers from across the country (see Table A3.1 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' instructional practice before the program. 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. Observations were conducted in the spring semester several months before the summer institute. 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

Table 3.1

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 <small>EF= Essential Feature A= Ability</small>	Important Understandings <small>U= Understanding</small>	Nature of Science <small>NOS= Nature of Science</small>
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: Observations 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		

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 (teacher or student) 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 pre-program lessons (see Table 3.1 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*

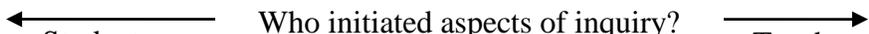
features of inquiry. As a result of this merger, a teacher could receive a score from zero to eight for the presence or absence of *abilities* and *features* of inquiry in a lesson. Scores for *understandings about inquiry* and aspects of NOS could range from zero to seven since there were seven aspects 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' pre-program lessons, we combined and modified 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 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 3.2). 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 3.2

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 →

Characterization of inquiry instruction. After establishing the presence of inquiry and who initiated the inquiry for all 26 teachers' pre-program 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" or "not having" a robust ability to teach science as inquiry. We then purposively selected eight teachers to interview from the group who did not demonstrate a robust ability to teach science as inquiry. These teachers were 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 their instructional practices (see APPENDIX at the end of the chapter for semi-structured interview).

Characterizing teachers' views of inquiry & NOS. Teachers' pre-program views were assessed using a validated, open-response, views of inquiry and NOS questionnaire. We developed the questionnaire over a period of two 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). Because there were slight differences between the questionnaire given to P1 teachers and P2 teachers we used only those items that were identical on the two questionnaires. We developed our scoring scale based on that of Lederman et al. (2002); however, we modified the original from a three-point scale (0-2; naïve, transitional, informed) to a four-point scale (0-3; uninformed, emerging, informed, 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 (see Table A3.2 for the views questionnaire and scoring rubric).

Relation of Views to Classroom Practice. Once we characterized teachers' pre-program classroom practice and their pre-program 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.

Characterizing the Nature of Teachers' Instruction

Presence of inquiry & NOS

Abilities to do inquiry and features of inquiry. 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 3.1).

The teaching of *abilities to do* and the *essential 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. (Application materials)

In this excerpt 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 Gabby and her students.

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.

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?

Gabby: 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.

Gabby: Right. Oxygen gives us more energy. (Classroom observation, 5-19-09)

This interaction took place at the very end of the class 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 explained she believed 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” (Interview, 8-6-09).

In most cases, few aspects of inquiry were evident in teachers’ lessons. Those aspects that were common across teachers 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.

Understandings about inquiry. 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 3.1).

Nature of Science. There was limited evidence of NOS instruction (see Figure 3.1). 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 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 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 nature of

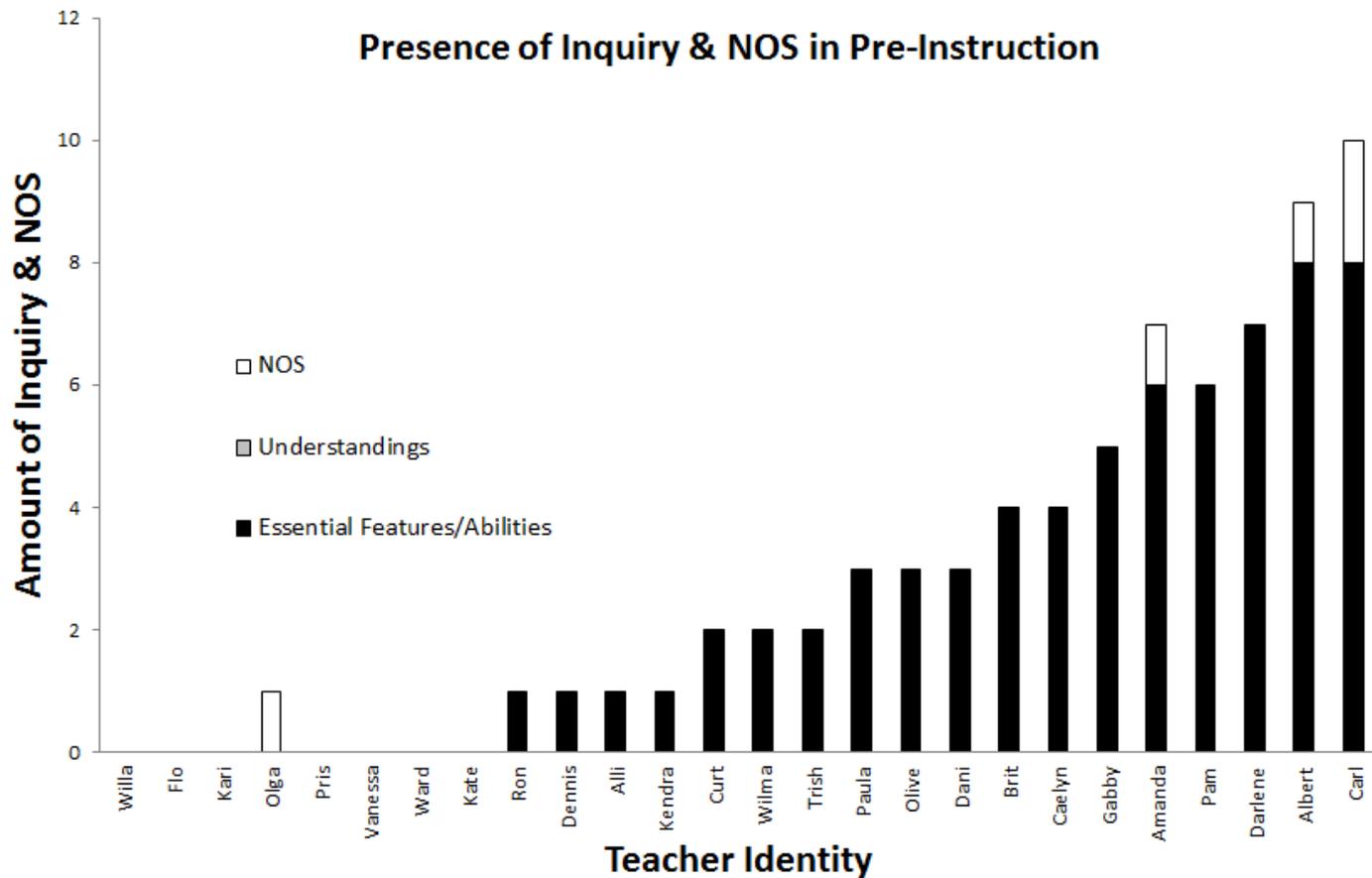


Figure 3.1. Shows the amount of the essential features/abilities of inquiry, understandings about inquiry, and NOS present in one lesson selected by a teacher prior to participating in the program

scientific knowledge 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 (teacher or student) initiated aspects of inquiry observed or described in teachers' lessons ranged from 0-25. The higher the number was, the more student-initiated the inquiry (see Table 3.3). These scores were determined using Table 3.2. 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 with respect to inquiry (see Table 3.2). 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 over the inquiry. 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

Table 3.3

Numerical scores for who initiated aspects of inquiry observed or described in lessons. The higher the number, the more student-initiated the inquiry

Teacher	Darlene	Carl	Paula	Albert	Amanda	Caelyn	Paula	Gabby	Dani	Brit	Olive	Wilma	Ron	Curt	Trish	Dennis	Alli	Kendra	Willa	Flo	Kari	Olga	Pris	Vanessa	Ward	Kate
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

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 germ-y 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 inquiries where the question was determined by the students. 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: 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 the lessons characterized as having more teacher-initiated inquiry 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 where the aspects of inquiry were fairly teacher-initiated. 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 to construct the lung, 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 the lab instructions she circulated, 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” (Classroom observation, 5-10-08). 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, guided the class through collecting data, and helped students 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.

Characterization of inquiry instruction

Figure 3.2 displays teachers’ scores for the amount of inquiry (*abilities* and *features* only) versus who initiated the inquiry. Most of the teachers’ lessons plot in the lower left quadrant of the Figure 3.2, while only a few teachers’ lessons plot in the upper right quadrant. The four teachers in the upper right quadrant demonstrated or described utilizing multiple aspects of inquiry in their teaching and engaged their students in less teacher-directed inquiry activities. We thus, characterized these

Amount of Inquiry vs. Who Initiated the Inquiry

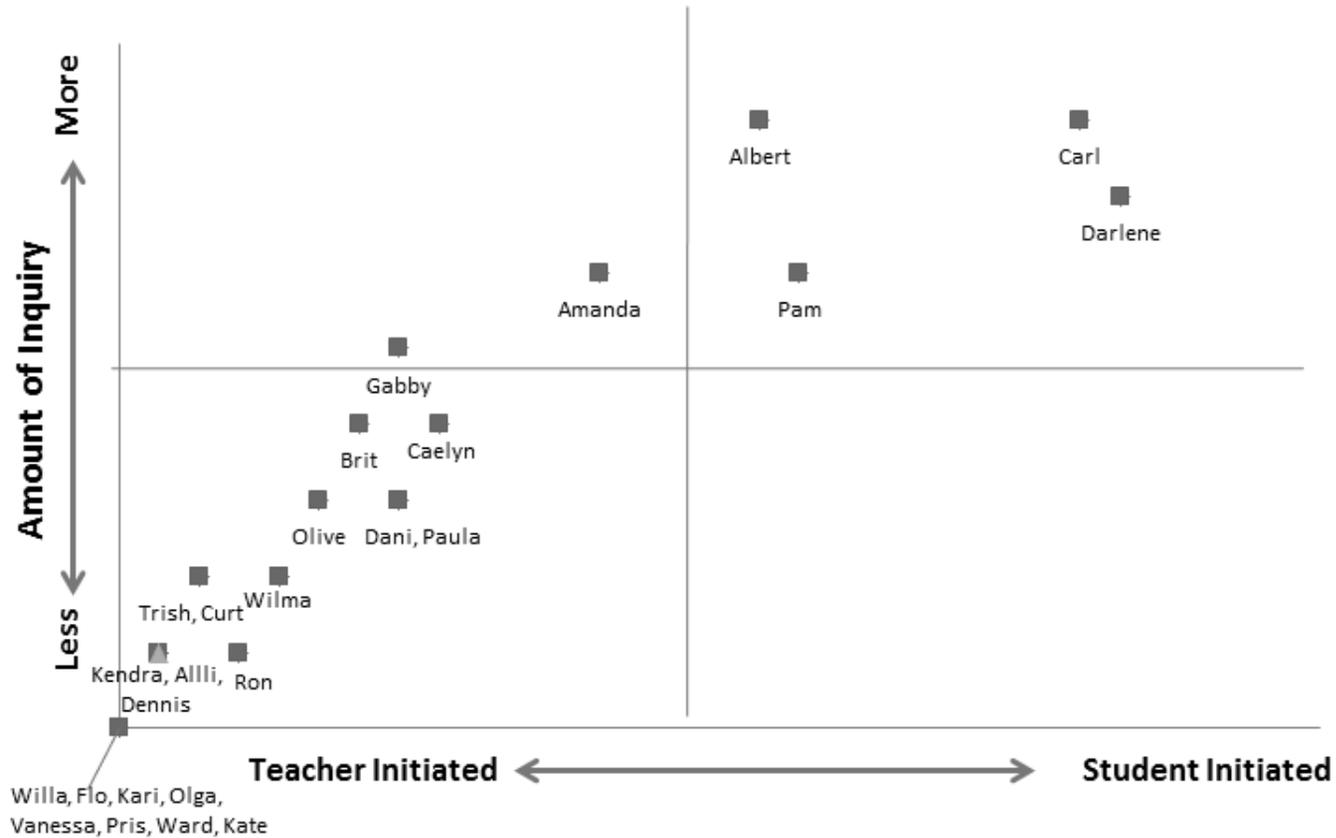


Figure 3.2. Amount of inquiry versus who initiated the aspects of inquiry observed in the lessons

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 that these teachers did not routinely 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). 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 (see APPENDIX at the end of the chapter for 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 as defined in reform-based documents. Six of eight teachers identified or described lessons that contained very little evidence of inquiry. The lessons described 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. 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"

(Interview, 8-6-09). Based on observational data, all but two of these six teachers plotted in the lower left-hand quadrant of Figure 3.2. 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' descriptions that included several aspects of inquiry were an ecosystems unit and a 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 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 anticipated might be common in these teachers instruction (see APPENDIX at the end of the chapter for semi-structured interview questions 10, 11, & 12). We analyzed these questions to determine if teachers were using the features of inquiry in their instruction, even though they might not have been able to articulate the nature of their inquiry 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 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. (Interview, 8-6-09)

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."- Gabby). 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 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, 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 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). 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 we 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 discussed in class. For instance, Flo explained that she had her students share their findings with parents at a science night. Students sung songs and made up raps about rocketry. An example she provided, “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 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. 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 Figure 3.2, 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 *abilities to do* and *essential features of inquiry*. In a small number of the classrooms, many of these aspects of 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 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. The amount of student initiation 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 having naïve, emerging, informed, or robust (0, 1, 2, or 3) understandings 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 3.3). 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 held naïve 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 in 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 teachers were characterized as naïve or emerging. Most teachers (16) gave responses that were considered naïve. Item 6 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 questionnaire, 8-9-08)

Views of Inquiry and NOS Scores

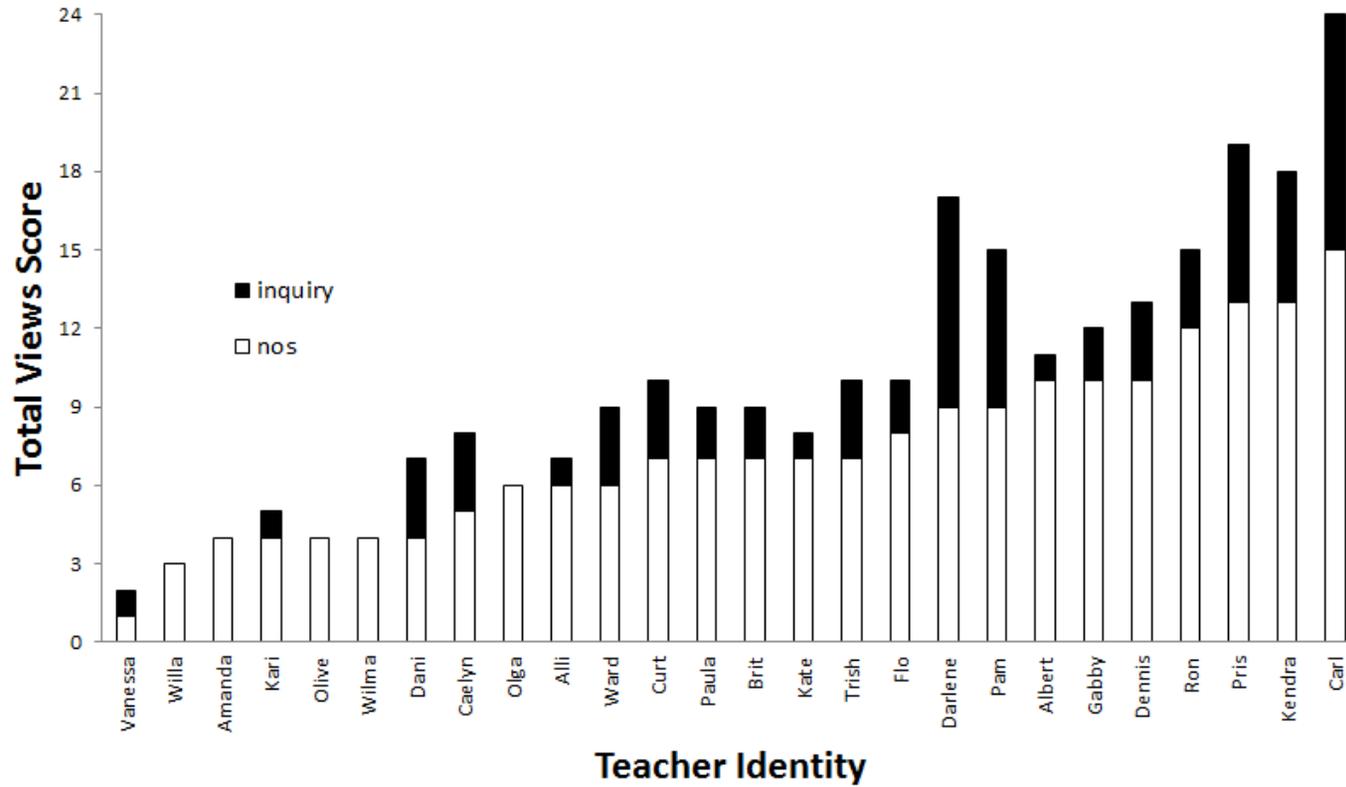


Figure 3.3. Teachers' views of inquiry and NOS measured by the views questionnaire

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

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 questionnaire, 8-9-08)

In his response, Carl 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*.

In response to item 7, which asked about the scientific method, most of the teachers (21/26) held naïve or emerging views. The average score on this item 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' 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 average score on this item was 1.0/3.0, or emerging. Eighteen of the teachers scored naïve or emerging on this item. Many of the teachers in these two groups were able to state what kinds of data might be collected, but they had trouble explaining what one would do with the data once they were collected.

Data from interview questions related to teachers' views of inquiry corroborated teachers' written responses. Few teachers verbally articulated views of inquiry that would be considered informed or robust. Those teachers that did articulate informed or robust views of inquiry in the interview also held more robust views on inquiry on the questionnaire. For example, even though Kendra struggled in describing what inquiry-based instruction was, 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, 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. (Interview, 8-5-09)

Whereas Amanda, a teacher who held more naïve views of inquiry, thought that 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. (Interview, 8-6-09)

Views of NOS. Views of NOS also varied across the sample; however, the average 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 all five items related to NOS, four teachers scored either naïve or emerging on all five items. Four other teachers scored informed or robust on all five items. The two lowest scoring NOS items were items 1 and 3. The average score on item 1 was 0.92/3.0, slightly below the emerging level. 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 they articulated that all science was experimental. The average score on item 3 was 1.1/3.0, 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 average score on item 5 (2.3/3.0) which dealt with differentiating between observations and inferences. 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

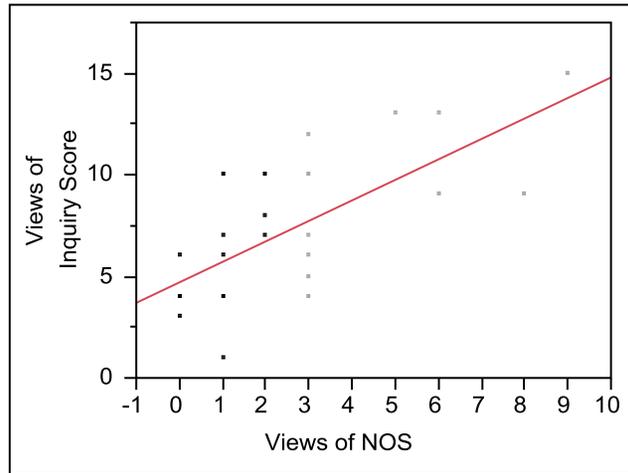
inference is what a scientist cannot see, parts of an atom” Vanessa, views questionnaire, 8-9-08).

Results from a simple linear regression model indicated there was a positive linear relationship between teachers’ views of inquiry and their views of NOS (see Figure 3.4). 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.

Summary. Teachers views of inquiry and NOS varied from uninformed to robust for each item. The average inquiry score was 0.87/3.0 suggesting 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 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 indicated 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 3.5. Teachers like Carl, Albert, Darlene, and Pam who used multiple aspects of inquiry in their pre-program



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 3.4. Correlation between views of inquiry and NOS scores

lessons also held more informed views of inquiry and NOS. These teachers plotted towards the right-hand side in both figures. Whereas teachers who used less inquiry generally held less informed views, plotting more towards the center or left of both figures. 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 Amanda and Pris. Amanda held fairly limited views of inquiry and NOS, but employed multiple aspects of inquiry in the lessons we observed, and Pris 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.

Results from simple linear regression models indicated there was a positive linear relationship between teachers' inquiry teaching score and their views of inquiry (Figure 3.6). There was also a positive linear relationship between teachers' inquiry teaching score and their views of inquiry and views of NOS summed score (Figure 3.7). 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

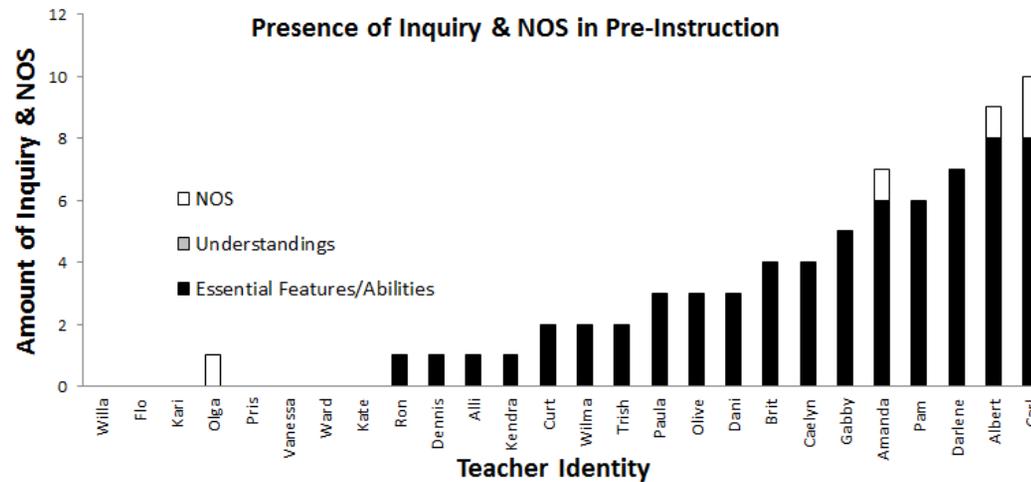
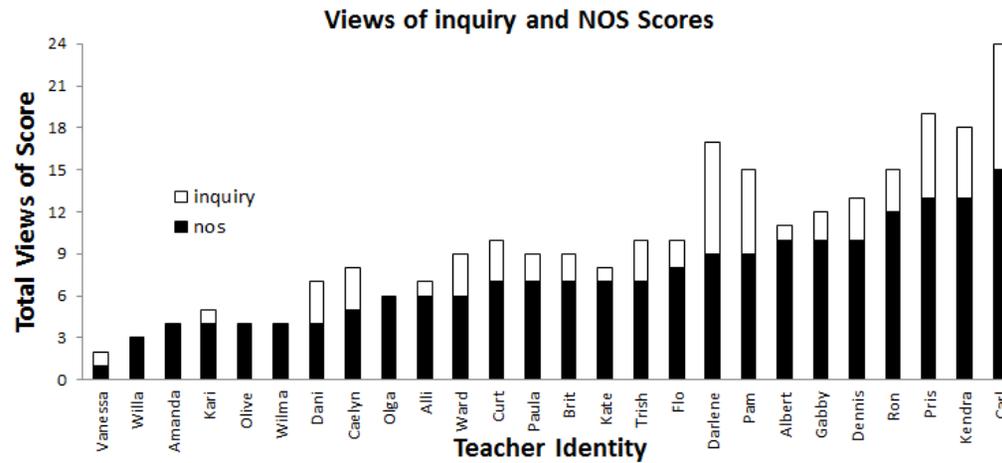
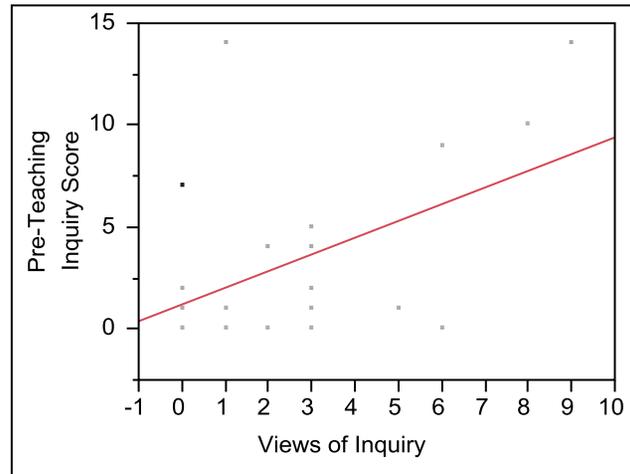


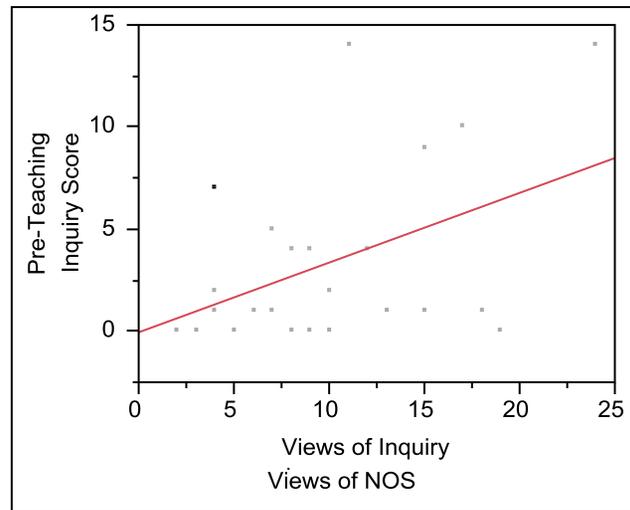
Figure 3.5. Displays a visual comparison between the teachers' views on inquiry and NOS and the presence of inquiry and NOS in their pre-program instruction



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 3.6. Simple linear regression comparing teachers' inquiry teaching score (abilities and features of inquiry) with their views of inquiry score from the views questionnaire



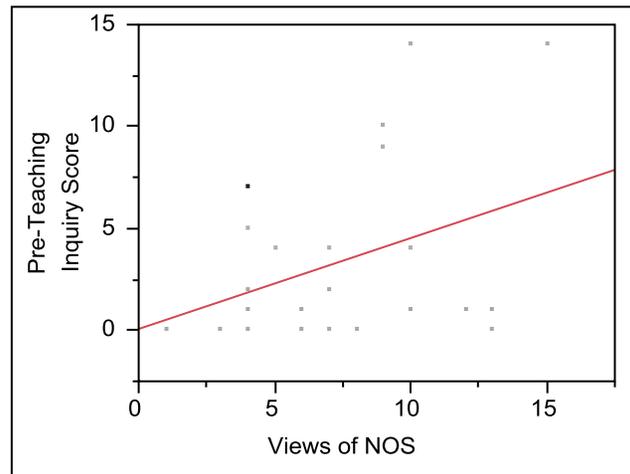
Analysis of Variance

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 3.7. 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 questionnaire

score. There was not a linear relationship between teachers' inquiry teaching score and their views of NOS (Figure 3.8). When the most anomalous scores were dropped from the sample (Amanda and Pris) the relationships between views and teaching practice become much stronger and all three relationships were significant.

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 in their interviews of aspects of inquiry that are congruent with those defined in reform-based documents. Only four teachers used words or phrases in their interviews that may have indicated inquiry. For example, the following comments were made by one teacher 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, 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.



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 3.8. Simple linear regression comparing teachers' inquiry teaching score (abilities and features of inquiry) with their views of NOS score from the views questionnaire

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 the apparent lack of empirical evidence for what is actually happening in classrooms across the U.S., 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. Inquiry-based instruction is a fundamental science teaching strategy. Throughout the past, reform movements have emphasized the importance of inquiry in helping students learn science (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 of scientific literacy (AAAS, 1989; Hodson, 1992; NRC 1996).

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 practice related to the *abilities to do* and *essential features of inquiry*. This variation was not surprising given the different backgrounds of the participant 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 ten 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 *abilities* and *features of 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 they described and we observed, we expected these teachers would select some of their better lessons as a best case scenario of their teaching 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 can make the assumption that inquiry-based instruction is probably even less common in the population of 5th-9th grade 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 they 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, 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 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 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 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.

Views of Inquiry & 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. 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 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 twenty 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

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 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 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 of these teachers. All of the 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 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 (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.

There are a few methodological limitations that need to be considered in the interpretations of this study. First, 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 they likely represent a best case scenario of what teachers know and what teachers are doing in their classrooms. Another constraint was that we only had a limited number of classroom observations. 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 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 representative of their instruction. Consequently, we feel our interpretations give as accurate of 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 in order to provide a more representative analysis of teachers' views and their practice related to inquiry and NOS.

Conclusions and Implications

Although reform-documents highlight the importance of inquiry and NOS and refer to inquiry as a central teaching strategy, this study indicates that even some of the best teachers cannot articulate adequate views of inquiry and NOS. Further they struggle to teach science in accordance with reform-based ideas. Findings from this study provide empirical evidence for what some researchers reported anecdotally; teachers are not teaching science in accordance with reform-based documents. 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 did not understand what inquiry-based instruction was 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 new standards close at hand, it is important to consider how we can better support teachers in understanding and enacting reform-based teaching approaches like inquiry. The findings from this study point to the critical need for first, a unified definition of inquiry-based instruction; second, better assessments 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 among academics and teacher educators as to what inquiry-based instruction actually is (Anderson, 2002). If the academic community has not reached consensus, how can we expect teachers to understand what inquiry is and to teach science in this way? The essential features of inquiry provide a working definition for inquiry-based teaching; however, it is uncertain how many teachers are familiar with these features. Have all teachers read the standards? Did teachers learn about the standards in their teacher education programs or through inservice education? We are unaware of studies documenting this. Studies like these might help us to know if teachers are receiving the same message regarding reform-based teaching. Finally, once the message is received, how is it interpreted? 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 ten years from now, where even the best teachers are not teaching science as inquiry.

The fact that many teachers believed they were teaching science as inquiry, but in reality were not, demonstrates teacher self-report alone will not provide an accurate picture of what teachers are actually doing in their classrooms. This highlights the need for better assessments to characterize teachers' instruction related to inquiry and NOS (Capps, Crawford, & Conzas, *in press*). 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 topics. In this study, we used aspects of inquiry defined in the standards (NRC 1996, 2000) and aspects of NOS suggested by Lederman et al. (2002) to develop our interview and observation protocols which 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 that 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 what inquiry-based instruction is and what it looks like and developing assessments of inquiry and NOS are imperative, however, this is not enough. Teaching science as inquiry and explicit instruction about NOS are complex and sophisticated instructional approaches. Supporting teachers in enacting new instructional approaches will demand significant PD (Crawford, 2000, 2007).

Teacher educators will need to 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. If teachers are unable to articulate their views of inquiry and NOS they will have difficulties teaching in accordance with these ideas. Preservice and inservice teachers will need opportunities to both engage in their own inquiries and practice teaching science as inquiry and about inquiry and NOS. Teacher educators can use these inquiry experiences to support teachers in learning how to emphasize aspects of inquiry and NOS in their own classrooms. If we expect educators to use new instructional techniques, they will need to have well designed opportunities and resources to learn and teach in this way (Loucks-Horsley Love, Stiles, Mundry, & Hewson, 2003).

APPENDIX

Table A3.1. *Background information for Fossil Finders teachers; pilot group 1 teachers are in white while pilot group 2 are shaded.*

Name	Grade	Education	Years teaching	College Sci Courses	Research Exp	Sci. PD Exp	Gender
Willa	5/6	BA-Psychology MS-Education	11	4	No	1	F
Dennis	5/6	BA-Int. Relations MS-Education	4	2	No	2	M
Vanessa	5/6	BA-Psychology MS-Education	5	1	No	9	F
Wilma	5/6	BA-Elem Ed MS-Education	4	1	No	3	F
Dani	7/8	BS-Biology MS-Education	9	16	Yes	1	F
Olive	7/8	BS-Biology MS-Education	4	23	No	3	F
Alli	7/8	BS-Biology MS-Education	5	13	Yes	3	F
Carl	8/9	BS-Geology MS-Education	30	31	Yes	14	M
Trish	9	BS-Biology MS-Education	13	26	No	3	F
Ward	8/9	BS-Earth Sci MS-Education	5	17	No	1	M
Amanda	5th-8 th	BA-Education MS-Education	5	6	No	5	F
Albert	5 th	BS-Electrical Eng.	14	15	Yes	2	M
Brit	6 th	BA-Elementary Ed	4	3	No	1	F
Curt	8 th	BA-Elementary Ed MS-Curr & Instr	9	10	Yes	1	M
Caelyn	5 th	BS-Elementary Ed	2	7	No	2	F
Darlene	7 th	BA-Fine Arts MS-Science Ed	10	7	Yes	4	F
Flo	6 th	BS-Physical Therp MS-Reading Ed	19	4	No	8	F
Gabby	8 th	BA-Anthropology Cert-Earth Sci Ed	5	16	No	3	F
Paula	6 th -8 th	BS-Elementary Ed MS-Science Ed	22	9	No	3	F
Kendra	7 th	BS-Biology MS-Teach & Learn	5	16	Yes	0	F
Kari	5 th	BA-Education MS-Elementary Ed	20	2	No	3	F
Kate	7 th	BS-Chemistry Cert-Science Ed	3	14	No	1	F
Olga	5 th	BS-Education	23	1	No	1	F
Pris	7 th	BA-Bio/Chem	22	32	Yes	4	F
Pam	7 th	BS-Elementary Ed	32	7	No	10	F
Ron	8 th	BS-Science Ed	2	21	No	1	M
AVG			11.0	11.7		3.4	

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?

Table A3.2. Views questionnaire and scoring rubric

Question	0 Uninformed/Naïve	1 Emerging	2 More Informed	3 Robust Understanding
1) Does science always involve doing experiments? Please explain your answer.	Yes it must. Maybe, maybe not (with no explanation)	Sometimes but should also note other ways of doing science, for example through observational or descriptive studies (but offers no example of such or explanation). Includes misconceptions.	Sometimes/often there are other ways of doing science, for example, observational or descriptive studies. Offers an example or an explanation.	The methods used in a scientific investigation depend on the question asked (e.g. some questions/hypotheses cannot be tested directly.)
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.	Demonstrates major misconceptions about what a theory. e.g. not proven “theories develop into laws (once they are proven correct)” or “ a theory is just a hunch.”, it’s a big idea, a guess No they don’t change or demonstrates major misconceptions other than theory-law distinction .	Theories are based on evidence, they are something we believe to be true Theories can/do change because of new information, data, discoveries or technology. However, makes no connection between data and evidence. May fall into this category because of theory-law issue, because someone with this issue really can’t be more informed.	Theories describe or explain, based on evidence Theories can change when new evidence weighs in against it (repeated testing). Answer must convey the importance of weighing evidence and includes no major misconceptions.	Explanatory framework, based on evidence (observed patterns), can generalize and predict (basically similar to 2, but beyond) Theory change requires the weighing of evidence, but theories are unlikely or difficult to change and answer includes no major misconceptions.
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	Does not know how to answer this question (e.g. “good question!”). or Responds that the events in question happened too long ago for us to really know, or were too violent/chaotic to be understandable. These theories are just opinions. or	Indicates that different people have different interpretations of events or different perspectives, but provides no further explanation other than different backgrounds or bias. May include misconceptions.	Indicates that different people (different scientists) have different interpretations of events or data, or different perspectives of such. Also provides a reasonable example or further explains. Includes no major misconceptions. Scientists use subjectivity	Indicates that different interpretations or perspectives arise because of socio/cultural factors (e.g. education, experiences) or because of creativity (or the idea of tentatively). Includes no major misconceptions. Scientists weigh evidence/judge arguments

<p>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.</p>	<p>The data are inconclusive, there is not enough data.</p>		<p>and creativity to form conclusions</p>	<p>and employ subjectivity/creativity. May also offer a social-constructivist explanation involving acceptance of the scientific community.</p>
<p>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.</p>	<p>Science is objective; there is no creativity in what scientists do. Or Science is subjective.</p>	<p>Indicates that creativity is important in some combination of the following: developing questions, experimental design, collecting and/or displaying data.</p>	<p>Indicates that creativity is important interpretation, analysis and or explanation but offers no explanation or example other than in terms of trouble-shooting</p>	<p>Indicates that creativity is important in all stages of scientific investigation and provides explanations or an example pertaining to interpretation, explanation, or the construction of an argument. And/or takes the social/constructivist perspective of scientific knowledge: scientific knowledge is socially constructed and culturally embedded (e.g. "human component").</p>

<p>5) Are observations the same as or different from inferences? Please explain your answer using examples.</p>	<p>No response or misconceptions on both observation and inference.</p>	<p>Accurately defines one term but not the other</p>	<p>Accurately defines one term, and closely approximates the second.</p>	<p>Accurately defines both terms without misconceptions (Observations can be made with only the five senses; Inferences involve a decision or interpretation being made about something you observe.)</p>
<p>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?</p>	<p>Does not know and/or demonstrates naive conceptions, for example equates inquiry with hands-on work, questioning, discovering/exploration.</p>	<p>Where students answer questions by collecting data. Answer may indicate student or teacher direction.</p>	<p>Where students give priority to data, i.e. Involves manipulating, summarizing, interpreting, displaying data. Using data as evidence. Answer may indicate that teachers facilitate or guide students.</p>	<p>Where students use data as evidence in developing explanations/interpretations for a phenomenon. Answer may indicate understanding of a balance between student and teacher direction (e.g. “there are different levels of inquiry based teaching.”)</p>
<p>7) What is the scientific method? Do all scientists use the scientific method? Please explain your answer.</p>	<p>I do not know, scientific method must be used, or good science must follow the scientific method.</p>	<p>Indicates that the scientific method is more flexible than commonly believed/taught: not all of the steps are always necessary, specific order of steps is not important.</p>	<p>Indicates that there are multiple methods of science (beyond the understanding as in 1). For example, not all science is experimental, or some scientific investigations are observational or descriptive.</p>	<p>Indicates that there are multiple methods of scientific investigation (as in 2) both within scientific discipline and across different scientific disciplines and/or science depends on questions</p>

<p>8) Explain the process a paleontologist might use to research how climate has changed throughout the geological past in NY.</p>	<p>No idea or... No mention of comparison. Might talk about data (e.g. rock type of fossils, but don't talk about what to do with it). Just mentions uniformitarianism, but no mention of data. Too vague.</p>	<p>Collecting data and comparing data (layers or sites) or comparing data across times (uniformitarianism). No "how" or "Why" in their answer. No explanation of how the evidence could be used to understand climate change.</p> <p>Just collecting data. Here are some of the kinds of data one could collect...</p> <p>(former answer: One or two of the ideas from robust with, explanation is absent or weak.</p> <p>Some form of data and the idea of using samples from from different times. Or just one good element from the 3 category)</p>	<p>Collects and compares as in emerging, and provides an explanation. Makes an explicit connection between organism or rock type and climate at different times (for example:)</p> <p>(former answers: Collecting data and explaining what the different kinds of data could indicate.</p> <p>Has all three ideas from robust: types of data to collect, comparing layers, and an explanation of how to use data, but provides weak explanation.</p> <p>Or has 2/3 of these with a strong explanation.</p> <p>Makes an explicit connection between organism or rock type and climate at different times (for example:))</p>	<p>Answer goes beyond collecting data and connecting it to the explanation. For example, ALSO indicates connecting to previous research, knows that both numbers and types of fossils are important kinds of data, describes several different rock types and what they indicate, includes several different sources of data and describes how they connect to different explanations).</p> <p>(former answer: Lists reasonable types of data to collect (rock type or sediment type, sedimentary structures, organisms, or chemical information in the rock), comparing layers at a site and across sites, and gives a valid explanation of how to use data to answer the question)</p>
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References

- Abd-El-Khalick, F. and Boujaoude, S. (1997) An exploratory study of the knowledge base for science teaching. *Journal of Research in Science Teaching*, 34, 673-699.
- Abd-El-Khalick, F., & Lederman, N.G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education*, 22(7), 665-701.
- Abell, S.K., & McDonald, J.T. (2004). Envisioning a curriculum of inquiry in the elementary school. In L.B. Flick & N.G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education*. Dordrecht: Kluwer Academic Publishers.
- Abell, S.K., & Roth, M. (1992). Constraints to teaching elementary science: A case study of a science enthusiast student teacher. *Science Education*, 76(6), 581-595.
- Ackerson, V.L. & Donnelly, L.A. (2008). Relationships among learner characteristics and preservice elementary teachers' views of nature of science. *Journal of Elementary Science Education*, 20(1), 45-58.
- American Association for the Advancement of Sciences. (1989). *Project 2061: Science for all Americans*. New York: Oxford University Press.
- American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

- Anderson, R.D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, 13(1), 1-12.
- Bell, C.A. (2002). Determining the effects of a professional development program on teachers' inquiry knowledge and classroom action: A case study of a professional development strategy. Unpublished doctoral dissertation, Purdue University, West Lafayette, IN.
- Blumenfeld, P., Soloway, E., Marx, R., Krajcik, J., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, 83, 701-723.
- Capps, D.K., Crawford, B.A., & Constan, M.A. (*in press*). A review of empirical literature on inquiry professional development: Alignment with best practices and a critique of the findings. *Journal of Science Teacher Education*.
- Carey, R.L., & Stauss, N.G. (1970). An analysis of experienced science teachers' understanding of the nature of science. *School Science and Mathematics*, 70(5), 366-376.
- Carey, S., & Smith, D. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist*, 28(3), 235-251.
- Cochran-Smith, M., & Lytle, S.L. (1999). Relationships of Knowledge and Practice: Teacher Learning in Communities. *Review of Research in Education*, 24, 249-305.
- Crawford, B.A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, 37(9), 916-937.

- Crawford, B.A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, 44(4), 613-642.
- Creswell, J.W. (2009). Research design: Qualitative, quantitative, and mixed methods approaches (3rd ed.). Los Angeles: Sage.
- Dewey, J. 1910. Science as subject matter and as method. *Science* 121-127.
- Duschl, R.A. (1990). Restructuring science education. New York: Teachers College Press.
- Fenstermacher, G. D. (1994). The Knower and the Known: The Nature of Knowledge in Research on Teaching. *Review of Research in Education*, 20, 3-56.
- Finson, K.D., Lisowski, M., Fitch, T., & Foster, G. (1996). The status of science education in K-6 Illinois schools. *School Science and Mathematics*, 96(3), 120-127.
- Gallagher, J. (1991). Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. *Science Education*, 75, 121-133.
- Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and their impact on instruction. In J. Gess-Newsome and N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (Dordrecht: Kluwer Academic), 51-94.
- Ginn, I.S., & Watters, J.J. (1999). Beginning elementary school teachers and the effective teaching of science. *Journal of Science Teacher Education*, 10(4), 287-313.
- Hashweh, M.Z. (1987). Effects of subject matter knowledge in the teaching of

- biology and physics. *Teaching and Teacher Education*, 3, 109–120.
- Haury, D.L. (1993). Teaching science through inquiry. ERIC CSMEE Digest, March. (ED 359 048).
- Hodson, D. (1992). In search of a meaningful relationship: An exploration of some issues relating to integration in science and science education. *International Journal of Science Education*, 14, 541-562.
- Jeanpierre, B., Oberhauser, K., & Freeman, C. (2005). Characteristics of professional development that effect change in secondary science teachers' classroom practices. *Journal of Research in Science Teaching*, 42(6), 668-690.
- Krajcik, J.S., Blumenfeld, P.C., Marx, R.W., & Soloway, E. (1994). A collaborative model for helping middle grade science teachers learn project-based instruction. *The Elementary School Journal*, 94(5), 483-497.
- Ladewski, B.J., Krajcik, J.S., & Harvey, C.L. (1994). A middle grade science teacher's emerging understanding of project-based instruction. *The Elementary School Journal*, 94(5), 499-515.
- Lederman, N.G. (1992). Students' and teachers' conceptions about the nature of science: A review of the research. *Journal of Research in Science Teaching*, 29, 331–359.
- Lederman, N.G. (2004). In L.B. Flick & N.G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education*. Dordrecht: Kluwer Academic Publishers.
- Lederman, N.G., Abd-El-Khalick, F., Bell, R.L., & Schwartz, R.S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of

- learners' conceptions of nature of science. *Journal of Research in Science Teaching*, 39(6), 497-521.
- Lee, C.A., & Houseal, A. (2003). Self-efficacy, standards, and benchmarks as factors in teaching elementary school science. *Journal of Elementary Science Education*, 15(1), 37-56.
- Lord, T., & Orkwiszewski, T. (2006). Moving from Didactic to Inquiry-Based Instruction in a Science Laboratory. *The American Biology Teacher*, 68(6), 342-345.
- Lotter, C., Harwood, W.S., & Bonner, J.J. (2007). The influence of core teaching conceptions on teachers' use of inquiry teaching practices. *Journal of Research in Science Teaching*, 44(9), 1318-1347.
- Loucks-Horsely, S., Love, N., Stiles, K., Mundry, S., & Hewson, P.W. (2003). *Designing Professional Development for Teacher of Science and Mathematics*, 2nd edition. Thousand Oaks, CA: Corwin Press, Inc.
- Luft, J.A. (2001). Changing inquiry practices and beliefs: the impact of an inquiry-based professional development programme on beginning and experienced secondary science teachers. *International Journal of Science Education*, 23(5), 517-534.
- McComas, W.F., Almazroa, H., & Clough, M.P. (1998). The nature of science in science education: An introduction. *Science & Education*, 7, 511-532.
- Minner, D.D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction – what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, 47(4), 474-496.

- Morey, M.K. (1990). Status of science education in Illinois elementary schools. *Journal of Research in Science Teaching*, 27(4), 387-398.
- National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.
- National Research Council. (2000). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.
- National Science Teachers Association. (1998). The National Science Education Standards: A Vision for the Improvement of Science Teaching and Learning. Arlington, VA: NSTA.
- Newman, W.J., Abell, S.K., Hubbard, P.D., McDonald, J., Otaala, J., & Martini, M. (2004). Dilemmas of teaching inquiry in elementary science methods. *Journal of Science Teacher Education*, 15(4), 257-279.
- Pajares, M.F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research*, 62(3), 307-332.
- Radford, D.L. (1998). Transferring theory into practice: A model for professional development for science education reform. *Journal of Research in Science Teaching*, 35(1), 73-88.
- Roehrig, G.H., & Luft, J.A. (2004). Constraints experienced by beginning secondary science teachers in implementing scientific inquiry lessons. *International Journal of Science Education*, 26(1), 3 - 24.
- Schwab, J.J. (1966). The teaching of science. Cambridge, MA: Harvard University Press.
- Schwartz, R.S., Lederman, N.G., & Crawford, B.A. (2004). Developing views of

nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, 88, 610–645.

Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4-14.

Stake, R., & Easley, J. (1978). Case studies in science education. Urbana, IL: The University of Illinois.

van Driel, J.H., Biejaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching*, 38(2), 137-158.

Wells, G. (1995). Language and the Inquiry-Oriented Curriculum. *Curriculum Inquiry*, 25(3), 233-269.

Windschitl, M. (2002). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education*, 87(1), 112-143.

CHAPTER 4

INQUIRY-BASED PROFESSIONAL DEVELOPMENT: WHAT DOES IT TAKE TO SUPPORT TEACHERS IN LEARNING ABOUT INQUIRY AND NATURE OF SCIENCE?

Abstract

This study examined science content knowledge and views of inquiry and nature of science (NOS) of a group of 5th-9th grade teachers, and their comparison teachers, before and after participating in an inquiry-based professional development (PD) experience. Project teachers participated in an intensive, week-long, resident institute during which they learned about geology, evolutionary concepts, NOS, and scientific inquiry while engaging in an authentic scientific investigation. They were also given support in how to teach these topics using an inquiry-based approach. Analyses of data indicate that project teachers showed greater gains in subject matter than comparison teachers and the relative change was significantly different statistically. Furthermore, most project teachers demonstrated a shift from less informed to more informed views of inquiry and NOS and the relative change between participant and comparison teachers was significantly different statistically. These gains are promising because they suggest that short-term and intensive PD can support teachers in enhancing their knowledge and views. Moreover, analysis of post-program questionnaires and interviews indicated that supporting teachers in reflecting on the relationship between their former classroom teaching practice, and new knowledge acquired during PD, may be an important link in enhancing teacher knowledge and

supporting teachers in changing their teaching practice. This suggests that enhanced knowledge and views may not be the only factor contributing to changing one's practice. The study points to the importance of reflection in promoting teacher change. Results from this study add insights into supporting teachers in enacting inquiry-based instruction in their classrooms.

Inquiry-based instruction and explicit teaching of nature of science (NOS) are important components of reform-based science teaching (NRC, 1996, 2000). Combining these two approaches is one way to promote scientific literacy (Hodson, 1992) and potentially contribute to improving both student achievement and engagement in science (AAAS, 1989, 1993; NRC, 1996). Unfortunately, few classroom teachers have had the opportunity to participate in scientific inquiry and even some of the most highly-qualified teachers have been shown to have limited knowledge of inquiry and NOS (Capps & Crawford, 2011). This lack of experience and knowledge puts serious limitations on many teachers' ability to teach through inquiry and about NOS. It is commonly thought that teacher knowledge affects classroom practice (Cochran-Smith & Lytle, 1999). Thus, the interaction between teacher knowledge and classroom practice related to inquiry and NOS is an important locus of study in science education research. We know that teaching through inquiry and about NOS are complex and sophisticated ways of teaching that demand significant professional development [PD] (Crawford, 2000, 2007; Lederman, 1999). Furthermore, it may be the case that active reflection plays a role in enhancing knowledge of these concepts (Schwartz, Lederman, & Crawford, 2004). Without PD support, including reflection, it is unlikely that teachers will be successful in enacting inquiry-based instruction or explicit NOS instruction in their classrooms.

To address the inconsistency between national reform documents that advocate inquiry and NOS instruction in science classrooms and what is actually occurring in most classrooms, we developed the Fossil Finders Project. Fossil Finders is a four-year research project that focuses on supporting 5th-9th grade teachers and their

students in learning about inquiry, NOS, earth science, and evolutionary concepts through an authentic research investigation. As part of the Fossil Finders project we created a two-year PD program aimed at enhancing teachers' understanding of inquiry, NOS, and science concepts; supporting them in reflecting on their knowledge and teaching practice; and preparing them to use inquiry-based instruction and explicit instruction related to inquiry and NOS in their classrooms. Effectively, our aim was to create a learning experience, "powerful enough to transform teachers' classroom practice" (Putnam & Borko, 2000, p.5). In this study we examined the following questions:

- 1) What was the impact of the PD on teachers' subject matter knowledge?
- 2) What was the impact of the PD on teachers' views of inquiry and NOS?

Moreover, as we analyzed the data, we saw evidence that some teachers were more reflective than others on their teaching practice after participating in the summer institute. This prompted us to look into the ways in which teachers were reflective and look for evidence that reflection might lead to gains in knowledge and changes in teaching practice.

Theoretical Framework

Teacher Professional Development

Teacher PD is regarded as a cornerstone for the implementation of reform-based teaching (Committee on Science and Mathematics Teacher Preparation, 2001). Although there is no single formula for effective teacher PD, there is consensus on a variety of features of PD that support teachers in learning and enacting reform-based instruction in their classrooms (e.g., Darling-Hammond & McLaughlin, 1995;

Desimone, 2009; Garet, Porter, Desimone, Birman, & Yoon, 2001; Loucks-Horsley, Love, Stiles, & Mundry, 2003; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Capps, Crawford, and Constat (in press) synthesized the literature on general teacher PD and specific inquiry-focused PD to develop a set of features of effective inquiry-based PD. Included in these features were: adequate time for teacher learning; extended support that goes beyond the initial PD workshop; opportunities to participate in authentic inquiry experiences during the workshop; curriculum and materials that are aligned with local, state, and national standards; opportunities to develop inquiry-based lessons during the workshop; opportunities to participate in modeled inquiry experiences during the workshop; time and support to reflect on one's experience; support transferring what was learned into the classrooms; and a focus on teacher content knowledge. Although each of these features is important, perhaps one of the most imperative features of effective PD is a focus on teacher knowledge (Birman, Desimone, Porter, & Garet, 2000; Kennedy, 1998). It seems intuitive that teachers who know more will be better teachers, whereas teachers who lack sufficient subject matter knowledge (e.g., an understanding of biological or geological principles) may have inadequate understandings or misconceptions (e.g., of inquiry and NOS) will struggle to teach their subject and have difficulties enacting teaching strategies like inquiry-based instruction. Thus, supporting teachers in enhancing their knowledge is crucial.

Teacher Knowledge & Reflection

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 in science includes: knowledge of specific science subject matter (e.g., geology, NOS), knowledge about what scientific inquiry is (both as a process and what scientists do), and knowledge about classroom inquiry (NRC, 2000). Reform-based practices like teaching through inquiry and about inquiry and NOS, are sophisticated ways of teaching that require a critical amount of content knowledge (Magnusson, Krajcik, & Borko, 2002). A teacher's practical knowledge also affects classroom teaching. Practical knowledge is the knowledge one has as a result of their teaching experience (Fenstermacher, 1994; van Driel, Beijaard, & Verloop, 2001). Practical knowledge has been characterized as dynamic and open to change (Elbaz, 1981). Thus, reflection on one's teaching experiences, knowledge, and/or views on teaching can be a valuable tool for teacher learning and teacher change (Dewey, 1933; Loughran, 2002; Schön, 1983). This is especially true as teachers enhance their knowledge through professional learning experiences. Reflection may help to situate new knowledge in one's classroom teaching, promoting change in practice. In considering classroom teaching practice related to inquiry, it is important to understand how both content knowledge and practical knowledge influence what teachers' know and what they do. As we better understand the interaction between these types of knowledge we will be better able to support teachers in developing sophisticated pedagogical skills including learning to teach science as inquiry and teaching about NOS.

Inquiry and Nature of Science

Scientific inquiry has been referred to as, "the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their

work” (NRC, 1996, p. 23). Scientific inquiry can also be thought of as science practiced by scientists (Chinn & Malhotra, 2002). Inquiry-based instruction resembles scientific inquiry by engaging students in instruction that parallels the work of scientists. In particular, the learner asks and answers scientifically-oriented questions, gives priority to evidence in responding to questions, comes up with explanations using evidence, connects explanations to scientific knowledge, and communicates and justifies explanations (NRC, 2000). At the heart of inquiry-based instruction is the learner, who through this process, grapples with data to make sense of some event or phenomenon. This type of instruction is important because it is grounded in current education theory and is congruent with how we think people learn. For example as learners investigate the natural world they construct meaning through their interactions with objects in the environment as well as with their peers and teacher (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Additionally, inquiry-based instruction provides a context to learn about NOS (S. Carey & Smith, 1993; Schwartz, et al., 2004).

Nature of science refers to an understanding of science as a way of knowing (Abd-El-Khalick, Bell, & Lederman, 1998). There are a variety of different viewpoints on the actual NOS. We take the position of Lederman et al. (2002) in the description of a set of seven aspects of NOS based in historical, philosophical, and sociological studies that are important and feasible to teach students. These aspects include the following: (a) scientific knowledge is tentative, (b) is partially subjective (i.e., theory laden), (c) relies on an empirical basis, (d) is creative, (e) is socially and culturally embedded, (f) is based upon observations and inferences, and (g) theories and laws are different forms of scientific knowledge. It has been suggested that implicit teaching of

NOS is not adequate and that these components should be explicitly taught in the classroom (Schwartz et al., 2004). Past studies have shown that many teachers and preservice teachers do not hold adequate views of NOS (Abd-El-Khalick & BouJaoude, 1997; Akerson & Donnelly, 2008; R. L. 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.

Purpose of the Study

A recent study revealed that a group of highly-motivated, well-qualified teachers believed they were teaching science as inquiry when, in actuality, they were not (Capps & Crawford, 2011). Furthermore, none of the teachers were teaching explicitly about NOS. Interestingly, few teachers in the study held adequate views of inquiry and NOS and there appeared to be a relationship between their views and their practice. This highlights the important need for PD that will support teachers in learning about inquiry and NOS and enacting this type of instruction in their classrooms. It has been argued that it is “difficult if not impossible to teach in ways in which one has not learned” (Loucks-Horsley et al., 2003, p.1). Thus, if we expect teachers to use new pedagogical approaches they will need to have learning experiences that familiarize them with these approaches, along with support in comparing how these learning experiences relate to their actual teaching practice. The purpose of this study is to describe changes in teachers’ knowledge and views after participating in a summer PD. The PD engaged teachers in inquiry-based experiences that aimed to provide support for them in articulating their views of inquiry and NOS.

Context of Study

This study was conducted within the Fossil Finders project. Fossils Finders: Using Fossils to Teach about Evolution, Inquiry, and Nature of Science is a multi-year National Science Foundation (NSF) funded project involving the collaboration between a large research university and a natural history museum/research institution. An innovative, two-year PD program was designed to support two pilot groups of teachers. The PD was combined with the development of innovative curriculum materials, the development of a website and database, and the opportunity for teachers and students to work with paleontologists on an authentic scientific investigation. A central focus of the PD was to support teachers in learning science content knowledge so they could later enact the curriculum and conduct the investigation with their students. The PD program targeted three areas: inquiry-based teaching strategies, nature of science, and geology and evolutionary concepts. This study focuses on the second pilot group during their first year of PD.

Teacher Professional Development: Summer Institute

The summer institute took place in the northeastern United States. The resident institute was held in early August at a university and a natural history museum, and it consisted of approximately 60 hours of instructional time. The primary goal of the institute was to create an authentic context to enhance teachers' understandings of science content knowledge including evolution, geology, views of inquiry, and views of NOS. Furthermore teachers were supported in learning inquiry process skills and in enhancing their teaching practice, towards a more inquiry-based approach (see APPENDIX at the end of the chapter for summer institute agenda). Teachers

experienced the Fossil Finders curriculum and materials as learners, participated in several paleontology/geology field trips, and collected and analyzed data as they took part in the scientific investigation. Further, teachers critically reflected on their experiences and their prior teaching.

Throughout the summer institute, instructors modeled each background lesson for the teachers. The lessons and instructional materials were designed to be inquiry-based. Special attention was given to explicitly highlighting aspects of inquiry and NOS in the lessons. Project teachers participated in these activities from the perspective of learners. Teachers also visited several field sites with scientists. The purpose of the field trips was to learn basic geological principles and how to identify fossils, and to better understand the overall geological context of scientific research study in the Devonian Period in central New York. Field trips were designed and lead by paleontologists with the support of education researchers. While in the field, teachers observed the rocks and fossils and were guided by scientists in making inferences about the geological history of each site and how the different sites related to one another. Participants collected rock and fossil samples from each site. These samples would later serve as reference sets and teaching samples in their classrooms. At one site, in Pompey, New York, teachers collected scientific samples for the actual Fossil Finders investigation to be done in classrooms. The samples were taken from specific stratigraphic layers as part of the research being carried out with the partnering paleontologists. Teachers analyzed some of these samples during the summer institute as they participated in the investigation from the perspective of learners. The entire investigation was modeled for teachers during the summer

institute. In conducting the lab work part of the investigation, teachers collected data from the samples they had gathered from the research site, measuring and identifying organisms in the rocks, and recording the degree of fragmentation of the fossils and the rock color. They then entered the data into an interactive online database connected to the Fossil Finders website (see Figure 4.1). Scientists supported teachers in using the data as evidence to make inferences about how marine organisms changed in response to environmental changes in the Devonian Sea. The remaining samples collected by teachers were shipped to each teacher's school and would be used when the teacher conducted the investigation with his or her students.

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

Fossil Finders Data Tools








Add Fossil Data to Sample: Dons-01-01A

Sub-Sample Id :	<input type="text" value="SS1"/>	Encrusters	Tail Length :	<input type="text"/>	mm
Genus :	<input type="text" value="Select.."/>	Zone No.	Tail Width :	<input type="text"/>	mm
Rock Color :	<input type="text" value="Select.."/>		Rib Segments :	<input type="text"/>	
Fragmentation :	<ul style="list-style-type: none"> Brachiopod - unidentified Branching Bryozoan - unidentified Bryozoan Encrusting - unid Clam - unidentified Crinoid - unidentified Horn Coral - unidentified Other - unknown Snail - unidentified Straight Cephalopod - unid Trace Fossil - unidentified Trilobite head - unidentified Trilobite ribs - unidentified Trilobite tail - unidentified Trilobite whole - unidentified 		Rib Length :	<input type="text"/>	mm
Length :	<input type="text" value="Clam - unidentified"/>		Image :	none	
Width :	<input type="text" value="Horn Coral - unidentified"/>		Note:	<input type="text"/>	
Surface Area :	<input type="text" value="Snail - unidentified"/>				






Figure 4.1. Screen shot from the data entry portion of the Fossil Finders database.

Participants

Twenty teachers were selected from an applicant pool of over 80 teachers. We assumed these teachers to be highly-motivated teachers seeking PD. Project teachers were selected based on the strength of their credentials and their declared desire to improve their science teaching. We strove to obtain an even distribution of 5th-9th grade teachers (see Table A4.1 for teachers' backgrounds). Selection criteria included: quantity of college science courses taken, presence or absence of science research experience, teaching experience (years), quantity of science PD, what they hoped to gain, their willingness to participate in the project, and evidence of a supportive school administration. In order to ensure heterogeneity we selected teachers with a range of coursework and experience. However, applicants in their first year of teaching service were not selected for the program since novice teachers generally have simplistic views of teaching and learning (Geddis, 1993). Additionally, studies have shown that new teachers are often unable to change their teaching practice or enact constructivist forms of instruction until they have had sufficient teaching experience combined with PD to reflect on their experiences (Adams & Krockover, 1997; Luft, 2001). Each of the selected teachers was paid a stipend for participating in Fossil Finders. They also received curriculum materials, a digital camera, and the use of a laptop computer. Because random assignment was not an option, we asked Fossil Finders teachers to select a comparison teacher. In selecting these teachers we asked participants to choose a comparison teacher who taught the same grade level and subject matter, and had similar teaching experiences and educational background, in order to approximate equivalence (Wayne, Yoon, Zhu, Cronen, & Garet, 2008). In most cases, comparison

teachers were located in the same school or school district. If this was not possible teachers were asked to find a comparison teacher from a school with similar characteristics to their own. Comparison teachers received a small stipend for their participation.

Data Collection & Analysis

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

Impact on teacher knowledge and views

An identical pre-post written instrument was administered online to participant and comparison teachers a week before and a week after the summer institute. The

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

Teachers' views of inquiry and NOS were assessed using a validated questionnaire. We developed the questionnaire, or the second part of the instrument, over a period of two-years drawing on elements of inquiry and inquiry-based instruction defined in *Inquiry and the National Science Education Standards* (NRC, 2000) and aspects of NOS reported to be accessible in K-12 classrooms (Lederman, et al., 2002). The views questionnaire consisted of 17-items, all of which were short answer and open-response (see A4.2 for the complete views questionnaire and scoring rubric). We developed our scoring scale based on Lederman et al. (2002); however, we modified the original three-point scale (0, 1, or 2) to a four-point scale (0, 1, 2, 3) representing naïve, emerging, informed, or robust understandings of inquiry and NOS. The four-point scale was finer grained and more clearly highlighted variance across our population of teachers. Thus, mean scores for each item are reported out of a total of 3.0. Initially, each item was scored independently by two researchers 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. Eighteen Fossil Finders teachers completed the pre-views questionnaire and 17 completed the post, whereas 15 comparison teachers completed the pre-views questionnaire and 10 completed the post. ANCOVA was again selected to assess treatment effects. Teacher

score on the pre-views questionnaire was used as the covariate in the analysis. We used the following model: $\text{change} = \text{pre score} + \text{treatment}$. Only those teachers who completed the pre and post-questionnaire were included in the model.

Linking new knowledge to practice through reflection

We reviewed responses to items on the post-instrument and post-interviews, conducted with a subset of teachers, to look for evidence of teachers linking new knowledge to their classroom teaching practice. Two categories of reflective comments emerged from our analysis: 1) Teachers identified aspects of their former teaching that were not congruent with what they had learned in the summer session, and 2) Teachers described how they would need to change their teaching to be more congruent with what they learned in the PD. After reflective comments were categorized, we looked for evidence that reflection might lead to gains in knowledge and changes in teaching practice.

Results

Analyses of the pre-post knowledge and views instrument revealed that during the course of the summer institute participant teachers significantly deepened their subject matter knowledge and views of inquiry and NOS. During the same time period there was no significant change in comparison teachers' subject matter knowledge or views (see Figures 4.2 & 4.3).

Impact on Subject Matter Knowledge

Analyses of pre-post assessments revealed that participant and comparison teachers' knowledge increased from the beginning to the end of the summer institute, but to different degrees. Participant teachers entered the program with higher scores

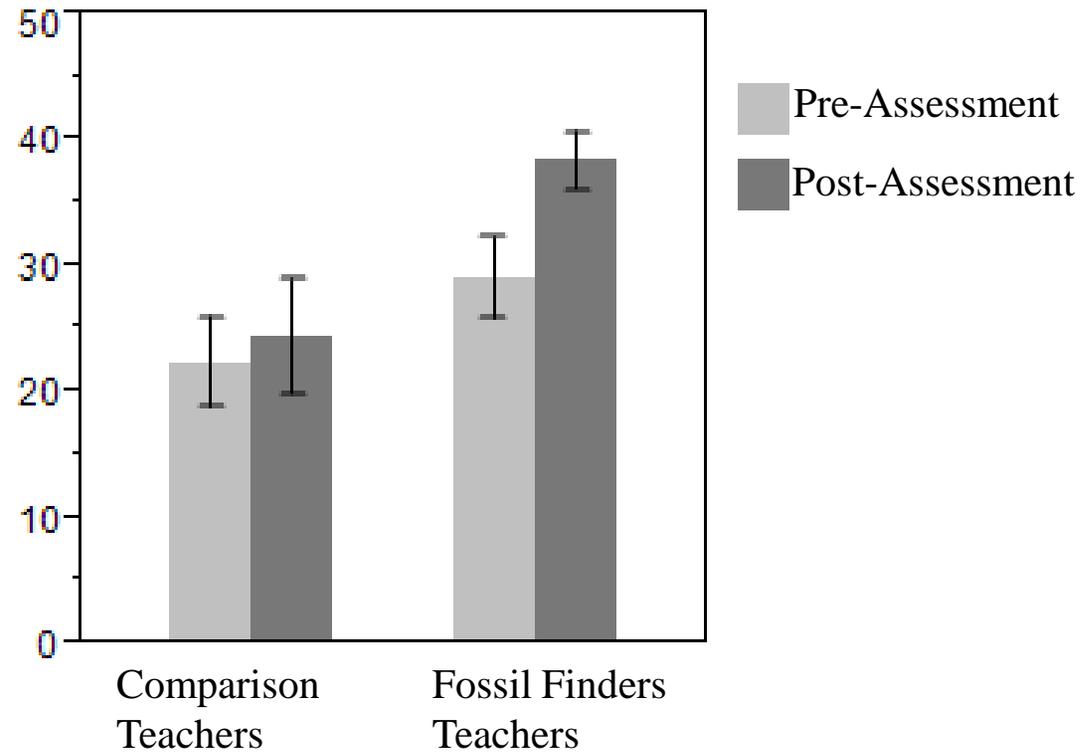


Figure 4.2. Mean subject matter knowledge pre-post assessment scores for comparison teachers (pre: n=15 post: n=11) and Fossil Finders teachers (pre: n= 18 post: n=18). Error bars were constructed using one standard deviation from the mean.

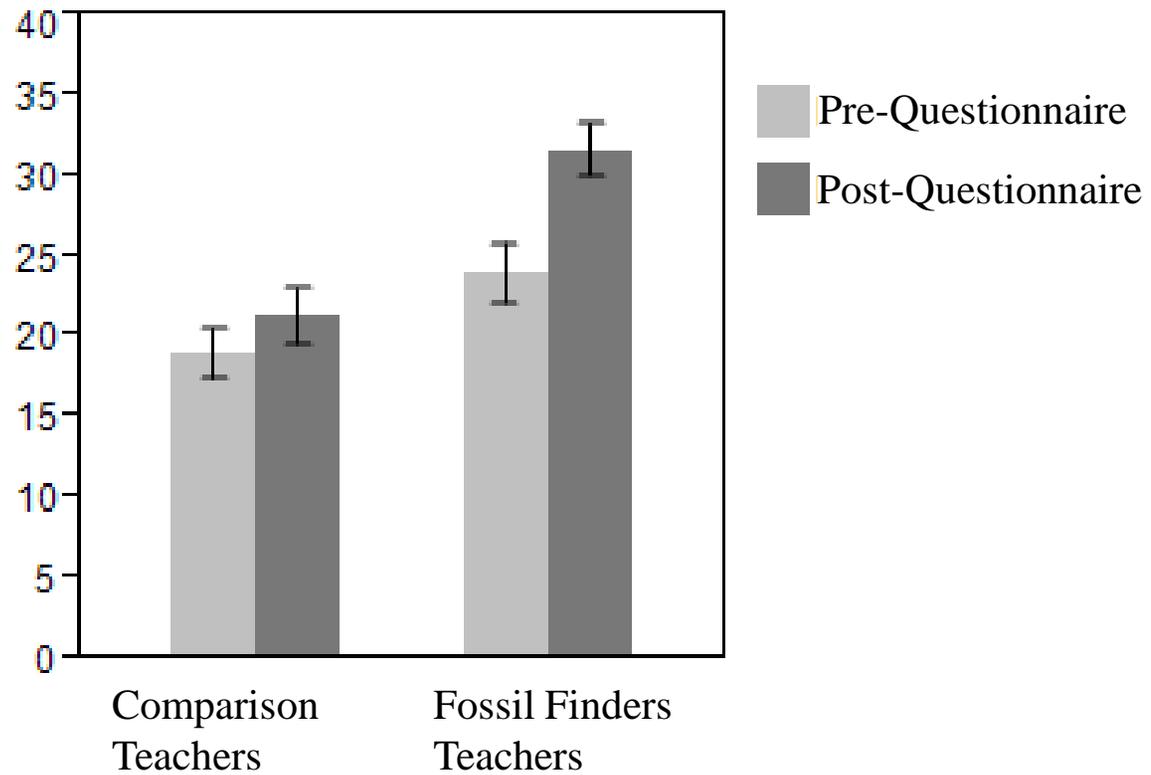


Figure 4.3. Mean views of inquiry and NOS pre-post questionnaire scores for comparison teachers (pre: n=15 post: n=10) and Fossil Finders teachers (pre: n=18 post: n=17). Error bars were constructed using one standard deviation from the mean.

than their comparison teachers (Participant: $\mu=29.00$, $\sigma=13.84$, $n=18$; Comparison: $\mu=22.33$, $\sigma=13.95$, $n=15$). This was not surprising given that participant teachers may have had more investment in the program than comparison teachers. After participating in the program participant teachers scores increased substantially whereas comparison teachers scores increased only modestly (Participant: $\mu=38.39$, $\sigma=9.79$, $n=18$; Comparison: $\mu=24.36$, $\sigma=14.99$, $n=11$). Results from ANCOVA, compensating for the difference in pre-program score, indicated the relative change of the treatment and comparison groups were significantly different statistically ($t = -2.94$, $p<0.01$) (see Table 4.1). Fossil Finders teachers scores increased by 32% whereas comparison scores increased by only 11% over the same period of time. The slight gains observed in comparison teachers' scores might be explained by test-retest effects. That is, having already seen the questions on the pre-assessment, many of the comparison teachers may have begun to think about them or perhaps even looked up information related to the items. The 32% increase in subject matter knowledge after a week-long PD was substantial. In particular, participant teachers exhibited the most improvement on items related to geologic concepts they worked on during the summer institute, including items related to the principle of superposition, organism identification, and fossilization (e.g., items 7, 11, and 14). Participant teachers also made gains on an item related to populations and ecosystems (e.g., item 13). Generally speaking, we observed greater changes for teachers who entered the program with limited subject matter knowledge and lesser changes for those who entered the program with more subject matter knowledge. For example, teachers who scored below 30 points on the pre-assessment had a mean change of 18 points on the post-

Table 4.1

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

	estimate	std error	t-ratio	p-value
intercept	10.21	3.53	2.89	0.0076*
pre	-0.36	0.11	-3.12	0.0044*
treatment	9.52	3.24	2.94	0.0068*
r^2	0.31			

assessment, whereas teachers who scored above 30 points on the pre-assessment had a mean change of only 2.5 points on the post-assessment.

Impact on Views of Inquiry & NOS

Analysis of the pre-post online questionnaire reflected a range of understandings of inquiry and NOS across participant and comparison teachers (see Figures 4.4 & 4.5). Both groups began with fairly limited views of inquiry and NOS (Participant: $\mu=23.90$, $\sigma=7.92$, $n=18$; Comparison: $\mu=18.86$, $\sigma=6.07$, $n=15$). Similarly to subject matter knowledge, participant teachers held slightly more informed views on inquiry and NOS than their comparison teachers prior to their participation. This was not surprising given that participant teachers may have had more investment in the program than comparison teachers. After the summer institute, participant teachers scores increased substantially where comparison teachers scores increased only modestly (Participant: $\mu=31.59$, $\sigma=6.60$, $n=17$; Comparison: $\mu=21.20$, $\sigma=5.43$, $n=10$). Results from ANCOVA, compensating for the difference in pre-program score, indicated the relative change of the treatment and comparison groups were significantly different statistically ($t = -4.46$, $p<0.001$) (see Table 4.2). Fossil Finders teachers scores increased by 31% whereas comparison scores increased by only 8% over the same period of time. The 31% increase in views of inquiry and NOS after a week-long PD was substantial, whereas the slight gains in comparison teachers' scores might be explained by test-retest effects. The largest gain by a comparison teacher, Patty, was equal to the average amount of change for participant teachers. However, the remaining comparison teachers showed very little change in their views of inquiry

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

Pre-Inquiry Views. Of the inquiry related questions participant and comparison teachers scored lowest on pre-questionnaire items that asked them to define inquiry-based instruction and to describe what it might look like in their classrooms (see APPENDIX at the end of the chapter for items 4.1 and 4.2). The mean score for participant teachers was 0.6 on item 4.1 and 0.7 on item 4.2. Mean scores for comparison teachers were 0.3 and 0.8 respectively. Eighty percent of teachers scored in the naïve and emerging categories on these items. Most teachers defined inquiry as hands-on or discovery-based learning. A typical naïve pre-program definition of inquiry-based instruction was illustrated in Jackie's pre-questionnaire response. She referred to inquiry as, "*Hands on, able to ask questions and then work together to solve the answers*" (Comparison teacher, 8-2-09). Only five teachers between both groups scored in the informed or robust categories on their pre-questionnaire definition of inquiry. These teachers went beyond describing inquiry as hands-on and gave responses that were congruent with the essential features of inquiry. Further, they recognized that there were variations on inquiry such as the amount of guidance provided by the teacher. One of these teachers defined inquiry as, "*The process of understanding scientific principles through engaging in questioning, experimenting and data collection to draw conclusions*" (Kelly, comparison teacher, 7-22-09).

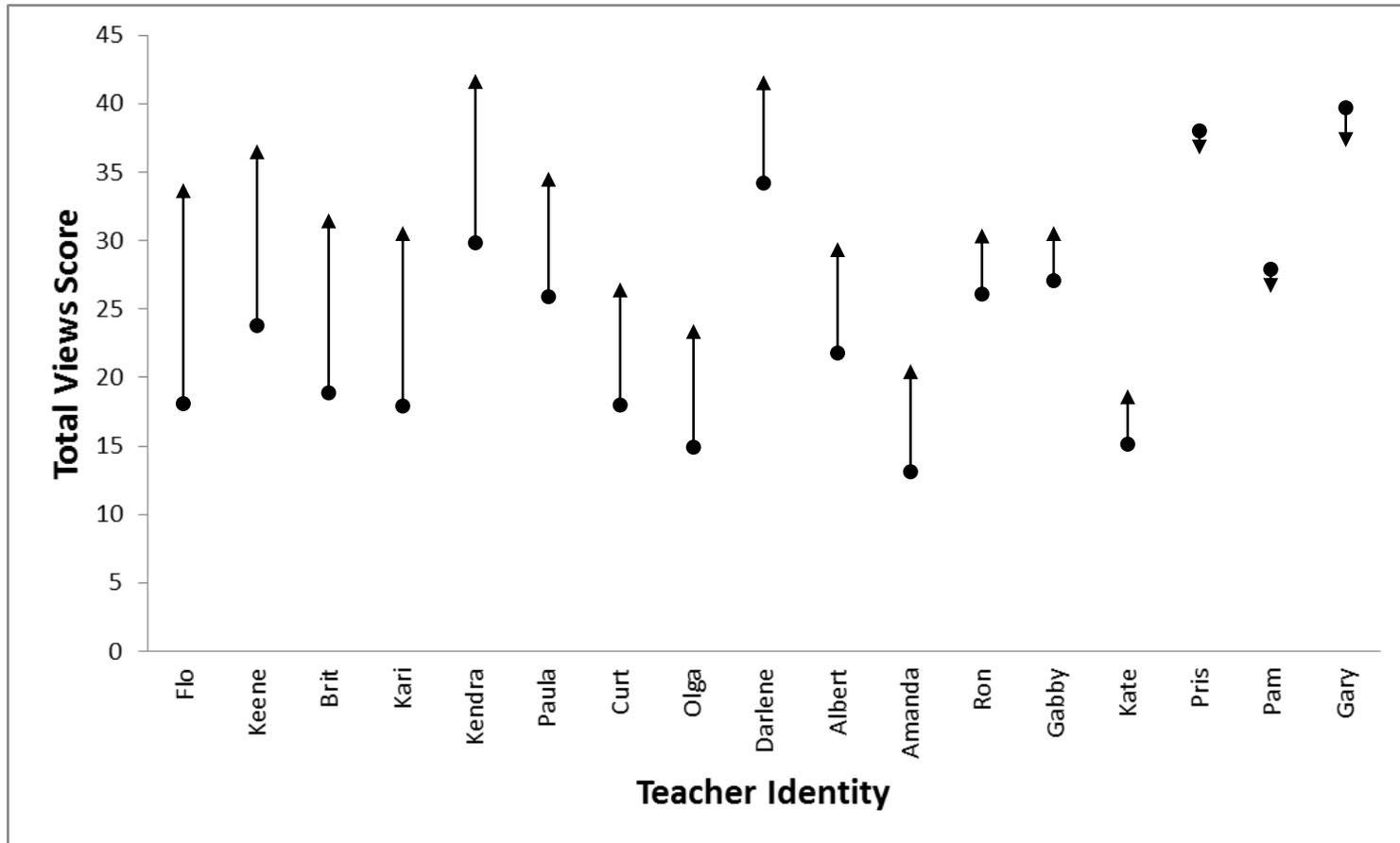


Figure 4.4. Participant teachers' views of inquiry and NOS before and after the summer institute measured by the views questionnaire. The point represents the pre-views score and the arrow represents change. Only participant teachers who completed the pre and post-questionnaire were included in this figure.

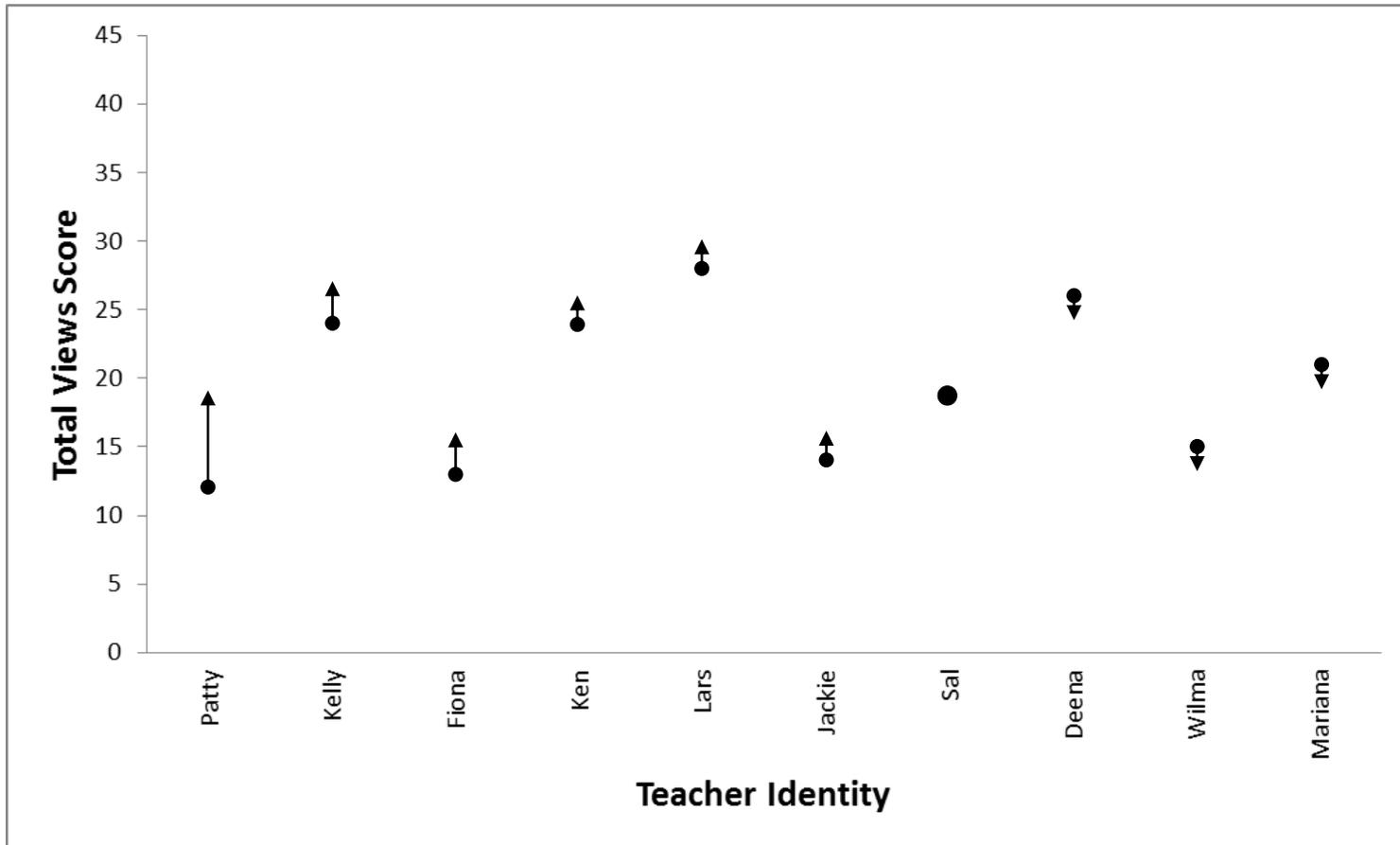


Figure 4.5. Comparison teachers' views of inquiry and NOS before and after the summer institute measured by the views questionnaire. The point represents the pre-views score and the arrow represents change. Only comparison teachers who completed the pre and post-questionnaire were included in this figure.

Table 4.2

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

	estimate	std error	t-ratio	p-value
intercept	8.28	2.46	3.37	0.0025*
pre	-0.34	0.11	-3.16	0.0043*
treatment	7.37	1.65	4.46	0.0002*
r ²	0.45			

Teachers scored the highest on an item that asked them to describe the benefits of inquiry-based instruction (item 5) and another item where they were asked to describe how confident they were in teaching science as inquiry (item 7). Over 75% of participant and comparison teachers recognized that inquiry-based instruction had the potential to increase student engagement and over 80% of participant and comparison teachers reported that they felt fairly confident in their ability to teach science as inquiry.

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

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

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

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

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

Pre-Views of NOS. Participant and comparison teachers' NOS scores were slightly higher than their inquiry scores on the pre-questionnaire. The lowest pre-questionnaire scores on NOS items were on items 8, 9, and 13 (see APPENDIX at the end of the chapter). Nearly 75% of participant teachers, and even a greater number of comparison teachers, scored in the naïve and uninformed categories when responding to items 8 and 9. These teachers viewed science as mainly experimental and thought of the scientific method as a procedure that most scientists followed in one way or another. A naïve response on item 9 described the scientific method as a step-by-step procedure. For instance, Caelyn said, "In general, I believe (I hope) most scientists use the scientific method. I believe it is a practical, step-by-step way to reach a scientific, evidence-based conclusion" (Participant teacher, pre-views questionnaire, 7-28-09). Only about 30% of participant and comparison teachers were able to describe the relationship between theories and laws at the informed or robust levels. These teachers recognized theories as explanatory and laws as descriptive. The remaining teachers viewed the relationship between theories and laws as hierarchical; that is, well tested

theories could eventually become laws. For example, Ken stated, “A scientific theory is a step below a law. A scientific law is a theory that has undergone rigorous testing and has always proven true” (Comparison teacher, pre-views questionnaire, 7-25-09). Of those items related to NOS teachers scored the highest on an item that asked them to describe the difference between observations and inferences (item 11) and an item that asked them to discuss if and how the work of scientists is influenced by society (item 15). Nearly 90% of participant teachers and 100% of comparison teachers were able to adequately describe the difference between observations and inferences. Moreover, 100% of participant teachers and nearly 90% of comparison teachers recognized that social norms, socio-cultural issues, and political issues influence science.

Post-Views of NOS. We also observed a marked post-assessment increase in participant teachers’ understanding of NOS. This was especially true on items 9, 12.1, 13, 14, & 16. Comparison teachers’ views improved on items 9 and 12.1, but their gains were not quite as large as those of participant teachers. The mean score for participant teachers on item 9 increased from 1.0 to 1.6. Many of these participant teachers demonstrated a better understanding of multiple methods used for doing science, depending on what question is asked. We also observed an increase in teachers’ understandings of theories and laws and how they related to one another. The mean score for participant teachers increased from 1.4 to 1.9 on item 12.1 and from 0.5 to 1.5 on item 13. Many more participant teachers than comparison teachers developed an understanding about theories and laws: that theories are not just hunches, but explanatory frameworks based on multiple observations, whereas laws are

descriptive statements that define observable phenomena. Furthermore, most participant teachers demonstrated an understanding that theories do not become laws, a common misconception that many teachers held, prior to the institute. For example in the pre-test, Keene stated,

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

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

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

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

Additional Findings

Linking new knowledge to practice through reflection. In total, six different teachers made reflective comments following the summer session. Five of the six teachers made reflective comments on the post-views questionnaire, five teachers made reflective comments in their interviews, and four of the teachers made reflective comments on both the post-views questionnaire and in interviews. As noted earlier, reflective comments fell into two categories that will now be discussed.

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

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

This comment shows that Olga was clearly connecting learning from the summer institute to her teaching prior to participating in the program. Interestingly, after the summer institute Olga and several other elementary teachers started to equate inquiry with the 5E Learning Cycle (Engage, Explore, Explain, Elaborate, and Evaluate). Olga felt the 5E Model was too complicated for her students so instead of 5E's she adopted 3E's. Equating inquiry with the 5E Model is not entirely correct, because a teacher could easily have her students engage, explore, explain, elaborate, and evaluate outside of the context of a scientifically-oriented questions where students are not giving priority to data. Olga did, however, recognize that many of her previous lessons were lacking a part where her students explained what they were observing, which is a very important component of inquiry. Another teacher, Kendra, who taught seventh

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

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

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

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

that her instruction before the institute was not inquiry and now recognized that she would need to make some revisions to her instruction.

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

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

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

We did not see evidence of reflective comments in the other thirteen teachers' post- questionnaires or interviews. In some cases the lack of critique or reflection can be explained by the fact that the teacher already held fairly robust views of inquiry and NOS (e.g., Darlene, Pris, Gary, and Paula) and may have already been teaching science in this way. However, in most cases the lack of reflection was likely due to the fact that the teachers' understanding of inquiry and NOS were insufficient to allow them to effectively reflect on their pre-institute teaching. Prior to the summer institute many of the teachers claimed they were confident teaching science as inquiry, even though we observed that their views on inquiry were quite limited. Following the summer institute many teachers maintained that their pre-institute instruction was inquiry-based, even though there was no evidence for this. For example, Amanda, a 4th-8th grade science teacher believed her pre-program instruction was inquiry-based.

When asked about her teaching after the summer institute she adopted a relativist view of inquiry (i.e., inquiry is in the eye of the beholder) writing,

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

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

Evidence that reflection may lead to enhanced knowledge and practice.

Interestingly, the teachers who made reflective comments on post-views questionnaires and interviews also demonstrated some of the greatest gains in their views on inquiry and NOS scores. The mean increase for all participant teachers on the views questionnaire was 7.4 whereas the six teachers who made reflective comments had a mean score of 11.2 ($\sigma=5.4$), suggesting teachers who were more reflective demonstrated greater gains in their views. Additionally, five of the six teachers who made reflective comments also described actual changes to their teaching practice on the post-questionnaire and/or interviews. For instance, in her questionnaire Pam wrote,

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

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

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

Here, Flo realized that turning questions back on her students, a practice used by the instructors in the summer session when she asked questions, might promote deeper thinking in her students. Therefore, instead of answering her students' questions right away, as was her custom before the summer institute, she began to incorporate this sort of questioning into her own teaching. Another teacher, Kendra, again talked about how her teaching before the institute was not quite inquiry and discussed how she had already changed some of her classroom instruction based on what she had learned in the institute. She said,

I think previous to coming to Fossil Finders I knew I was doing activities in my class but I didn't realize that I wasn't quite doing inquiry. So, I was having students...be active in class and have things

at their table and manipulate things at their table, even collecting data, but not really having them do inquiry. Not really giving them a question to answer, um not even kind of closed inquiry. So I think um more of a clarification of what inquiry is. And then I have been able to do a little bit of that in my class already. (Kendra, participant teacher, post-interview, 9-28-09)

Although these comments were reported by teachers and not directly observed, it was interesting that comments about actual change were only reported in those cases in which teachers made reflective comments in post-surveys and interviews. This suggests that reflection may be an important step in teacher change.

Discussion

The Fossil Finders PD program was designed to support teachers in learning about geology, evolutionary concepts, NOS, and scientific inquiry; with the hope they would later translate this knowledge into their teaching. Findings from this study indicate that short-term, yet intense PD that engages teachers in an authentic scientific investigation provides pedagogical support, and assists teachers in connecting their own learning with their classroom teaching can result in substantial increases in teacher subject matter knowledge and views of inquiry and NOS. Most importantly, this kind of PD can support teachers in linking new knowledge with their classroom teaching practice.

Impact on Subject Matter Knowledge

Gains in subject matter knowledge were most pronounced for those teachers who entered the program with limited prior knowledge. This was not surprising given these teachers had greater potential for growth than those who entered the summer institute with more subject matter knowledge. Nonetheless, it was promising to see

that teachers with limited subject matter knowledge were able to enhance their knowledge in a short period of time through an inquiry-based experience. This suggests that short-term PD focusing on an authentic investigation can be effective in enhancing teachers' subject matter knowledge. These findings are similar to those of Minner, Levy, & Century (2010) who suggested that student learning, especially related to science concepts, could occur by engaging them in an investigation. Furthermore, it supports the assertion that it is possible to effectively learn subject matter knowledge through inquiry (e.g., Anderson, 2002; Geier et al., 2008; Hmelo-Silver, Duncan, & Chinn, 2007; Shymansky, Kyle, & Alport, 1983) and highlights the importance of engaging teachers in learning experiences similar to those they will be expected to enact in their classrooms (Garet et al., 2001; Loucks-Horsley et al. 2003).

Impact on Views of Inquiry and NOS

We expected to see the greatest gains in views scores, as we did for subject matter, in those teachers who held very limited views of inquiry and NOS. Other studies have shown results of this nature (e.g., Schwartz et al., 2004). However, this was not the case. For example, Kendra, who entered the program with fairly informed views of inquiry and NOS made large gains while Kate who entered the program with limited views of inquiry and NOS made only modest gains. In general, gains in views were most pronounced for those participants who entered the program with more moderate understandings of inquiry and NOS suggesting there may be some threshold of understanding related to inquiry and NOS that an individual must acquire before greater changes in views can occur. This is similar to the findings of Capps & Crawford (2010) who observed that two teachers who entered a PD program with very

limited views of inquiry and NOS made only modest gains in their views where a teacher who entered the program with a stronger foundation made more pronounced gains. Perhaps short-term PD may be insufficient to increase teachers' views of inquiry and NOS if they have not reached this threshold. Inquiry and NOS are abstract, multifaceted constructs and may therefore be more difficult to grasp (Crawford, 2000, 2007; Lederman, 1999) and will likely require much more support. Another interesting point is that the majority of participant and comparison teachers entered the program confident in their ability to teach science as inquiry, even though their conceptions of inquiry did not align with ideas put forth by the *National Science Education Standards*. This suggests there is some confusion between what teachers understand about inquiry-based instruction and how inquiry is defined in reform-based documents. Left unchecked, the initial confidence, or self-efficacy, that many appeared to have about these teaching approaches would likely result in a lack of change in views, as was the case for Brenda and Hank in the study by Schwartz et al. (2004). In the Schwartz et al. study, these two preservice teachers had a lot of confidence in their initial views and because of this, saw no need for change.

Linking New Knowledge to Practice through Reflection

In order for teachers to enact reform-based practices, like inquiry-based teaching and explicitly teaching about NOS, they will need adequate subject matter knowledge as well as an understanding of inquiry and NOS (Lederman, 1999; Luft, 1999; Shepardson & Harbor, 2004). Overall, most of the participant teachers in this study made gains in their subject matter knowledge and views of inquiry and NOS. Some made great leaps, whereas others' gains were more modest. Gains in knowledge

may be necessary, but not sufficient to promote reform-based teaching. There are many other factors that influence classroom teaching practice (Shepardson et al., 2004). One of the factors that appeared important in this study was the ability to connect knowledge to practice. During the PD, we actively supported participant teachers in articulating their views on inquiry and NOS, and we assisted them in comparing their views and teaching practice to images of inquiry and NOS in the literature. This process, along with completing the questionnaires and participating in interviews, appeared to be influential in supporting some teachers in thinking more deeply about how their views related to their classroom practice. Six teachers recognized inconsistencies between their pre-program views and instruction, and what they learned during the PD. Not surprisingly, these were some of the teachers who made the greatest gains in their views of inquiry and NOS after the summer institute. Furthermore, five of these teachers reported changing their teaching practice based on their new knowledge. Based on our findings we propose that *active reflection* may be important in enhancing teacher knowledge and could be a significant intermediary step in changing one's classroom teaching practice.

There are several limitations of the study that need to be addressed. For example, there was a lack of established initial equivalence between the participant group and the comparison group. This methodological limitation is common in non-experimental studies in education research. In order to minimize the lack of equivalence we asked participant teachers to select teachers with a similar background and student population. Another limitation relates to test-retest effects. Because the same assessment was given to participant and comparison teachers before and after the

summer institute it was possible that teachers could have learned from the assessment. Although there were slight gains in comparison teachers post-assessments the change was not significant, whereas we observed significant change for participant teachers. A third limitation was that we employed teacher self-report in order to discuss teachers' intent to change and actual change in teaching practice. Thus, we cannot know for sure if these changes actually did occur, or if the teachers discussed these changes in order to please us. In a related study, we follow several participant teachers into their classrooms after the PD in order to understand how the PD experience impacted their classroom teaching practice (Capps & Crawford, in prep).

Conclusions & Implications

Our first conclusion is that short-term, yet intensive PD experiences that engage teachers in an authentic investigation can effectively enhance teachers' subject matter knowledge. One of our findings related to this conclusion was that teachers who entered the summer institute with limited subject matter knowledge showed the greatest gains, whereas those who entered the institute with greater subject matter knowledge showed more modest gains. Our second conclusion is that short-term PD can be effective in enhancing teachers' views of inquiry and NOS. Interestingly, the greatest gains did not occur for those teachers with limited knowledge of inquiry and NOS as was the case for subject matter knowledge. This suggests that having a basic level of foundational knowledge related to inquiry and NOS may serve as a launching point to acquiring deeper knowledge related to inquiry and NOS. We did not explore what the actual threshold might be, but suggest this as an area for further investigation. Our third conclusion is that active reflection on one's views and teaching practice may

help to solidify new knowledge and assist in anchoring this knowledge in one's teaching practice. In this study teachers who actively reflected on their views and teaching practice made the greatest gains in their views of inquiry and NOS scores after the summer institute. Many of these teachers also began to discuss how they might change their teaching practice and some teachers even provided evidence of how they had already changed their practice based on what they learned in the PD.

Results from this study have some important implications for teacher PD. As in our study, it is possible that some teachers might appear to make large strides towards reform-based teaching in relatively short periods of time, but they will likely be in the minority. The fact that not every teacher made large gains in knowledge or in thinking about changes to their practice highlights the need for high-quality PD that extends beyond the initial PD work session. Some teachers will need more time and support to articulate these difficult concepts and assimilate them into their understandings and, finally, into their practice. PD that provides support for teachers in reflecting on their views and how their views relate to their teaching practice may be an effective way to support teachers in learning about and enacting reform-based teaching in their classrooms. However, this will not be easy. We know that teachers' views, knowledge, and practice are difficult to change (Pajares, 1992; Richardson, 1996). Support must be explicit, sustained, and ongoing. One way to support teachers is through web-based resources, like on-line teacher discussion boards. These may be effective in extending learning opportunities for teachers by facilitating teacher discussion and reflection outside of the initial PD. Over ten years-ago Putnum & Borko (2000) called for better technological tools to support teacher learning.

Unfortunately, many of the web-based resources we experimented with as part of our PD were time consuming and cumbersome, requiring teachers to spend additional time logging-in and learning new programs. Thus, we believe there is a need for more powerful and easier to use tools that can keep teachers and professional developers in contact with one another, thus promoting continued teacher reflection and learning. In addition to developing PD opportunities that will promote teacher learning, professional developers will need to establish strong relationships with teachers, based on trust (Fulton & Britton, 2001), so teachers will feel comfortable to talk freely about how their views relate to their teaching practice.

APPENDIX

Summer institute agenda



Summer Institute Agenda SUNDAY, August 10, 2008

6:00 pm - 7:30 pm	Registration and Pre-instrument
7:30 pm - 9:00 pm	<p>Welcome, Introductions, Project Overview and Dinner <i>Educational project overview</i> <i>Goals of Educational Research</i> <i>Goals of Scientific Research</i> <i>Goals of Collaboration</i></p> <p><i>Get teachers to choose sandwiches for tomorrow afternoon.</i></p>

MONDAY, August 11, 2008: Nature of Science, Inquiry, and the Fossil Finders Project

8:00 am - 9:00 am	<p>Focus Groups: What does good science teaching look like? Teachers brainstorm what good science instruction looks like. As a group make a list of top 10 aspects of good science teaching. **Discuss resources for good science teaching. Where can we go, who can we consult? Introduce teachers to Inquiry and the NSES Standards (NRC, 2000) as well as other resources.</p>
9:00 am - 9:50 am	Introduction to Nature of Science and Inquiry: Tricky Tracks
9:50 am - 10:20 am	Nature of Science & Introduction to Structure and Function
10:20 am - 10:30 pm	Break
10:30 am - 11:15 am	What do geologists do?
11:15 am - 12:00 pm	Scientific Research Talks
12:00 pm - 12:30 pm	Lunch Break
12:30 pm - 2:30 pm	Field Trip Part 1: Lithological Variation & Changing Environments
2:30 pm - 6:00 pm	Field Trip Part 2: Biodiversity
6:00 pm - 8:00 pm	Picnic Dinner

TUESDAY, August 12, 2008: Authentic Science in the Classroom

8:30 am - 12:00 am	<p>Digging into the Devonian: <i>Nuts and bolts of paleontology</i></p> <p>Museum Tour</p>
12:00 pm - 12:30 pm	Lunch
12:30 pm - 1:00 pm	<p>Introduction and Philosophy of Fossil Finders Curriculum/Rationale for background lessons - <i>Rationale for designing curriculum: NOS, Inquiry, and science content.</i></p>
1:00 pm - 3:20 pm	<p>Implementation/Feedback on Background Curriculum and connection to NYS-Standards <i>Exploration of Fossils and Classroom Population Study lessons</i> **Discussion on the order of background lessons and how things can be combined/added ***Connections to NSES and state standards</p>

3:20 am - 3:30 pm	Break
3:30 pm - 5:30 pm	Identification and Measurement of Devonian Fossils Sorting Activity Tour of Fossil Collection Fossil Identification Engage participants in identifying fossils

WEDNESDAY, August 13, 2008: Collecting Fossils and Fossil Finders Curriculum

8:30 am - 12:30 pm	Field Work 1: Measuring section, making observations, and collecting samples for classroom use
12:30 pm - 1:00 pm	Lunch
1:00 pm - 1:50 pm	Debrief field trip <i>*Science- What did you do? What did you learn? What are some inferences you can make based on your observations?</i> <i>**Education- How can you translate this into the classroom? How does it relate to students/curriculum?</i>
1:50 pm - 2:00 pm	Break
2:00 pm - 4:30 pm	Fossil Finders Investigation <i>*Teachers will collect data from the samples they collect. They will do the basic collection all students will do as well as more advanced data collection.</i>
4:30 pm - 5:00 pm	Wrap-up and discuss findings. How will teachers use this information in their classes to make interpretations about the rocks their class investigated
6:00 pm - 7:30 pm	Dinner & Discussion about Curriculum Adaptations (ELL) <i>½ hour lecture on culture, science education and ELL, ½ hour open discussion</i>

THURSDAY, August 14, 2008: Collecting Fossils, Curriculum, & Data Collection for Investigation

8:30 am - 12:30 pm	Field Work 2: Measure section, make observations, and collect samples for classroom use
12:30 pm - 1:00 pm	Lunch
1:00 pm - 2:20 pm	Debrief and compare field experiences <i>*Science- How do the sites we visited relate to one another, similarities/differences? Discuss change over time and distance. How can you use what you learned to help make interpretations about the past?</i> <i>*Finish-up compiling data and lead teachers through interpretations based on data.</i> <i>**Education- How does your work in the field relate to "real science" and NOS? Further ideas about bringing this into the classroom...</i>
2:20 pm - 2:30 pm	Break
2:30 pm - 3:30 pm	Bringing the Fossil Finders Investigation into the Classroom: Teacher Input and Adaptations (Split up by grade level and have teachers discuss)
3:30 pm - 5:00 pm	TBA What kinds of resources might you need? <i>*Help teachers use computers and cameras to make resources for their classroom.</i>
6:00 pm - 8:00 pm	Dinner & Discussion about Evolution and Religion -Evolution by natural selection

FRIDAY, August 15, 2008: Website, Planning, and Evaluations

8:30 am - 10:30 am	Technology: Computers, Website, etc... <i>* Walk teachers through website. Talk about what they can use their technology for. Continued resource development if teachers feel comfortable with computers.</i>
10:30 am - 12:00 pm	Planning Curriculum Implementation: Expectations and Scheduling <i>Have calendars and sign-up sheets. Discuss when to do pre/post instruments, data collection, etc...</i>
12:00 pm - 1:00 pm	Lunch
1:00 pm - 2:00 pm	Virtual Fieldwork Experiences Creating a field work experience without going into the field
2:00 pm - 3:30 pm	Extensions: Grade Level & Student Research <i>Discuss how class data can be compared to other classes. Use teacher data and compare it to PRI collected data.</i>
3:30 pm - 4:30 pm	Post Instruments and Wrap-up ***Program Evaluations will be done remotely

Table A4.1. Background information for Fossil Finders teachers in pilot group 2.

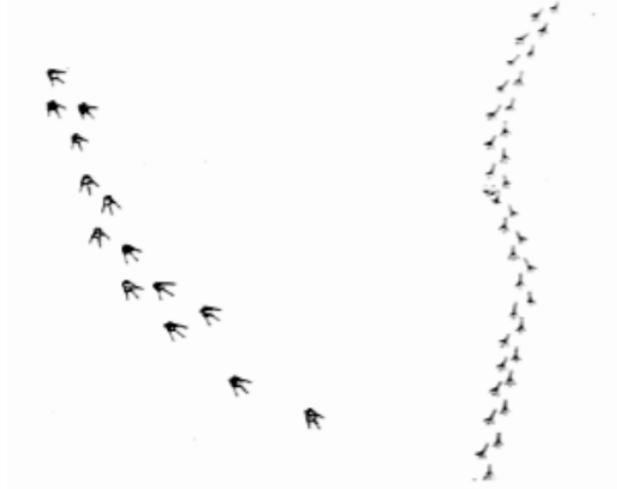
Name	Grad	Education	Years teaching Exp	College Sci Courses	Research Exp	Sci. PD Exp	Gender
Amanda	5 th -8 th	BA-Education MS-Education	5	6	No	5	F
Albert	5 th	BS-Electrical Eng.	14	15	Yes	2	M
Brit	6 th	BA-Elementary Ed	4	3	No	0	F
Curt	8 th	BA-Elementary Ed MS-Curr & Instr	9	10	Yes	1	M
Caelyn	5 th	BS-Elementary Ed	2	7	No	2	F
Darlene	7 th	BA-Fine Arts MS-Science Ed	10	7	Yes	4	F
Flo	6 th	BS-Physical Therp MS-Reading Ed	19	4	No	8	F
Gabby	8 th	BA-Anthropology Cert-Earth Sci Ed	5	16	No	3	F
Paula	6 th -8 th	BS-Elementary Ed MS-Science Ed	22	9	No	3	F
Kendra	7 th	BS-Biology MS-Teach & Learn	5	16	Yes	0	F
Kari	5 th	BA-Education MS-Elementary Ed	20	2	No	3	F
Kate	7 th	BS-Chemistry Cert-Science Ed	3	14	No	1	F
Olga	5 th	BS-Education	23	1	No	1	F
Pris	7 th	BA-Bio/Chem	22	32	Yes	4	F
Pam	7 th	BS-Elementary Ed	32	7	No	10	F
Ron	8 th	BS-Science Ed M.Ed-TESOL	2	21	No	1	M
Keene	6 th -8 th	BS-Biology M.S. Entomology	6	18	Yes	3	F
Gary	7 th	BA-Bio & Chem MS-Biochem	13	25	Yes	2	M

List of instruments

- M. L. Rutledge & M. A. Warden (2000). Evolutionary Theory, the Nature of Science & High School Biology Teachers: Critical Relationships. *The American Biology Teacher*, 62 (1), 23-31.
- J. C. Libarkin (2008). GCI Concept Inventory: GCI v.2.1.1
- New York Regents Physical-Earth Science High School Examinations, August 2008, June 2008, January 2008, June 2007, June 2006
- J. Dodick & N. Orion (2003). Measuring Student Understanding of Geological Time. *Science Education*, 87 (5), 708-731
- New York Regents Living Environment High School Examinations, January 2009, January 2008
- D. L. Anderson, K. M. Fisher, & G. J. Norman. (2002). Development and Evaluation of the Conceptual Inventory of Natural Selection. *Journal of Research in Science Teaching*, 39 (10), 952-978

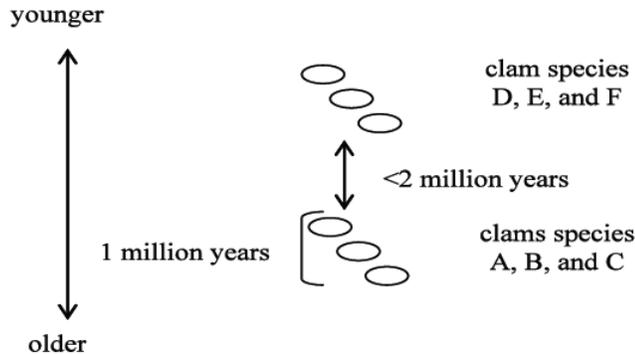
Teacher pre-post written knowledge assessment

Use the picture below to answer Questions 1 and 2.



1. Write one statement about the tracks that is an **inference**.
2. Write one statement about the tracks that is an **observation**.
3. Which of the following phrases accurately describe(s) the processes of biological evolution? Please select all statements that apply.
 - A. Change in the gene pool of a population
 - B. Change in an individual organism as it matures
 - C. Conscious decision by a group of organisms to adapt in response to environmental change
 - D. Change in an individual organism as it struggles to survive in its environment
 - E. The change in populations due to the process of natural selection
 - F. The accumulation of new variation in the gene pool through genetic mutations
 - G. A population that has changed genetically is unable to breed with other populations of the original species
 - H. The change in populations through time as a result of environmental change
4. Which of the following statements explain how the fossil-bearing rocks of Central New York became hard? Please select all statements that apply.
 - A. After the sea level went down, the sun baked the sediments, causing the material to harden into rock.
 - B. Sea water above the sediment exerted pressure on the sediments at the sea bottom, causing the sediments to harden into rock.
 - C. Many hundreds of meters of sediments piled up in the sea bottom, eventually causing the sediments to compact.
 - D. Organisms living on the sediment pushed down on the sediment surface, causing compaction.
 - E. Powerful waves pushed down on the sediment, causing sediment compaction.
 - F. Ions dissolved in water in the pore spaces of the sediment precipitated, "cementing" the rock together.

Use the picture below to answer Question 5.



5. Imagine that you are looking at abundant fossil clams in a thick sequence of strata at a particular site. Several species of clams are present throughout many meters of rock at the bottom of the sequence, representing about a million years in a constant environment. Then, fossils of these clam species disappear, and several other species of clams are present throughout the upper part of the rock sequence. You don't know how much time passed between the change in clams (and there may be missing time from the geologic record), but you have reason to believe it is less than 2,000,000 years. Given the information available, which of the following is (are) reasonable explanations for these observations? Please select all statements that apply.

- A. A change in predation caused several species to disappear, permitting less vulnerable species to move into the area.
- B. There was no change over time. All the sediments were deposited at the same time, and the heavier shells were deposited in the bottom part of the sequence.
- C. A change in sea level led to a fundamental change in the local environment. This change caused the local extinction of several species, followed by the immigration of the other species.
- D. An ecological catastrophe, perhaps low bottom-water oxygen levels, caused the extinction of several species, followed by the migration of several other species into the area.
- E. The environment changed. The original group of species adapted to the changes and evolved into the new species.
- F. There was no environmental change. Natural selection caused the older clam species to evolve into the new species.
- G. There was no environmental change. The new species migrated into the area, via a new opening to another marine basin. The new species outcompeted and displaced the original clam species.
- H. There was no change over time. Both groups of species were always present, but during time interval one only one group was preserved, and during time interval two only the other group was preserved.

6. Natural selection is often considered the main mechanism by which evolution occurs. Which of the following is **not** a part of Darwin's theory of natural selection? Please select all statements that apply.

- A. Individuals of a population vary.
- B. Organisms tend to have far more offspring than survive to reproduce.
- C. There are limited resources for which individuals of the same species compete.
- D. Modifications an organism acquires during its lifetime are passed to its offspring.
- E. Variations possessed by individuals of a population are heritable.

7. Imagine that you are looking at three different marine rock exposures that contain fossils, including some that are good index fossils. Your job is to estimate the relative ages of the rocks based on those fossils. Below is a table that contains fossils in sequence in each geologic section.

Location 1	Location 2	Location 3
gastropod species A	gastropod species B	clam species A
clam species B	belemnite	sea urchin
Coral	gastropod species A	gastropod species B
ammonite species B	clam species B	gastropod species C
ammonite species A	ammonite species B	Belemnite

What is the sequence of all 10 fossils from oldest to youngest?

_____ OLDEST

_____ YOUNGEST

8. When conducting fieldwork, geologists sometimes notice that at one location the index fossils seem to *skip* a species that is present in another location. Which of the following are **unlikely** explanations for the absence of some species in the rock exposures at different locations? Please select all statements that apply.

- A. The rock from that particular time interval might be missing from one section, because no sediments were deposited in that location at that time.
- B. Sediments were deposited in that location at that geologic interval, but they were eroded away before the next layer was settled.
- C. Sediments were deposited at that location at that geologic interval, but glaciers eroded them all away.
- D. Sediments were deposited in that location at that geologic time interval, but that particular index fossil isn't present because the animal didn't live in the area at that time.

9. Based on fossil evidence, most scientists make which of the following inferences? Please select only one statement.

- A. life has not changed significantly throughout Earth's history.
- B. life has evolved primarily from complex to simple forms.
- C. most species of organisms that have lived on Earth are now extinct.
- D. mammals developed early in the Precambrian time period.

10. Imagine that you are in an area of terrestrial sedimentary rock containing the skeletons of dinosaurs, ranging from dinosaur eggs in nests, to newly hatched babies, to mature adults.

Describe the processes that occurred in order for these dinosaur remains and eggs to become preserved.

11. Please list and describe three ways to distinguish a brachiopod from a bivalve in Devonian Period rocks.

12. The fossil below was found in surface bedrock in the eastern United States.



Which statement best describes the formation of the rock containing this fossil? Please select only one statement.

- A. The rock was formed by the metamorphism of sedimentary rock deposited in a terrestrial environment during the Cretaceous Period.
- B. The rock was formed by the compaction and cementation of sediments deposited in a terrestrial environment during the Triassic Period.
- C. The rock was formed by the compaction and cementation of sediments deposited in a marine environment during the Cambrian Period.
- D. The rock was formed from the solidification of magma in a marine environment during the Triassic Period.

13. Limited food resources might have which of the following effect(s) on a population of marine filter feeding organisms of a particular species? Please select all statements that apply.

- A. The average individual in the population of the species decreases in size.
- B. The population of the species goes extinct.
- C. The individuals compete with each other for access to food, usually causing lethal injuries.
- D. Individuals of the population actively begin mutating so they will be better suited for the environment..
- E. The number of individuals in the population decreases.

14. Fossils are studied by scientists interested in learning about the past. Which of the following are not examples of fossils? Please select all statements that apply.

- A. Plant leaves preserved in volcanic ash from the Cretaceous Period
- B. An imprint of a clam shell preserved in Devonian shale
- C. The excrement of a Jurassic dinosaur
- D. Bones of a hominin (ancient human) found in rocks of the East African Rift Valley
- E. The carbonized remains of a bacterium found in the chemical sedimentary rock known as chert
- F. A spearhead found in central New York
- G. Wood, in-filled and replaced by minerals (petrified wood)
- H. A Miocene-age shark tooth found in loose sand deposits in Maryland
- I. A snail shell recently washed up onto a sandy beach
- J. A 20,000 year-old frozen woolly mammoth from Siberia preserved with bones and flesh

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

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

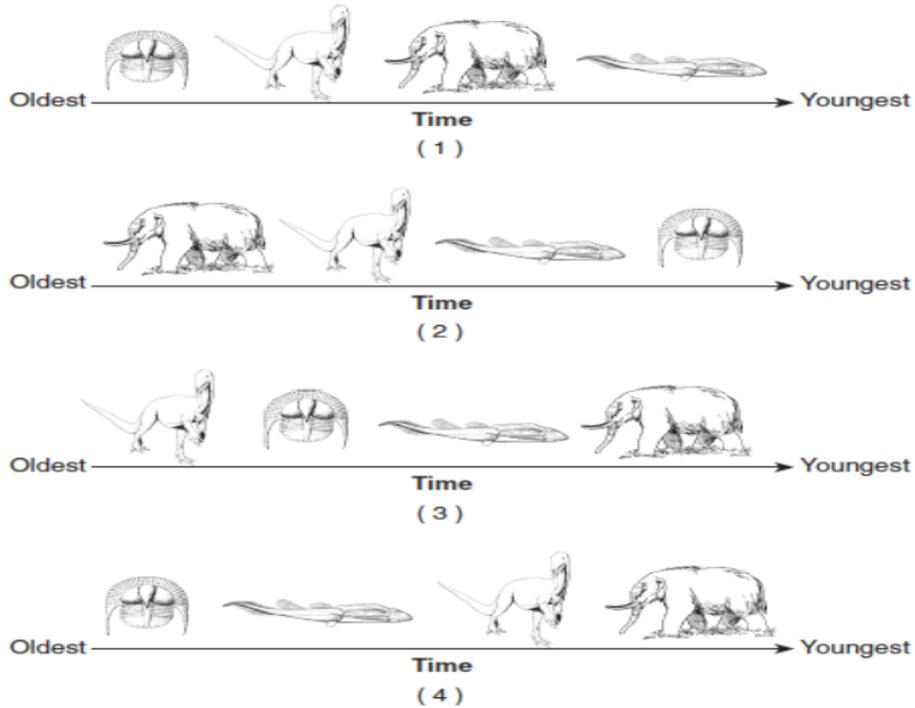
16. Which of the following observation(s) provide evidence for evolution that cannot be explained by pre-Darwinian notions of Creationism? Please select all statements that apply.

- A. Species of organisms show patterns of similarity to each other often called "hierarchical" or "nested", echoed in the Linnaean system of classification.
- B. Fossils in the rock record show change through geologic time.
- C. Anatomical traits of organism all seem to have been independently engineered.
- D. Organisms are adapted to their environments.
- E. All species of organisms possess every anatomical feature that could be useful for their survival.
- F. All species possess vestigial anatomical structures and pieces of genetic code.
- G. Groups of organisms are geographically distributed in ways that suggest evolutionary histories.

17. What is the primary origin of sand, silt, and mud that make up the rocks of central New York? Please select only one statement.

- A. Rocks on the sea bottom were weathered and eroded by waves that pounded along the shore and currents that ran along the bottom.
- B. Organisms living along the sea bottom eroded the sea bottom rocks through their activities.
- C. Wind broke up rocks and carried sediment out to sea.
- D. Rocks on land were weathered into sediment, which washed into the sea via creeks and rivers.

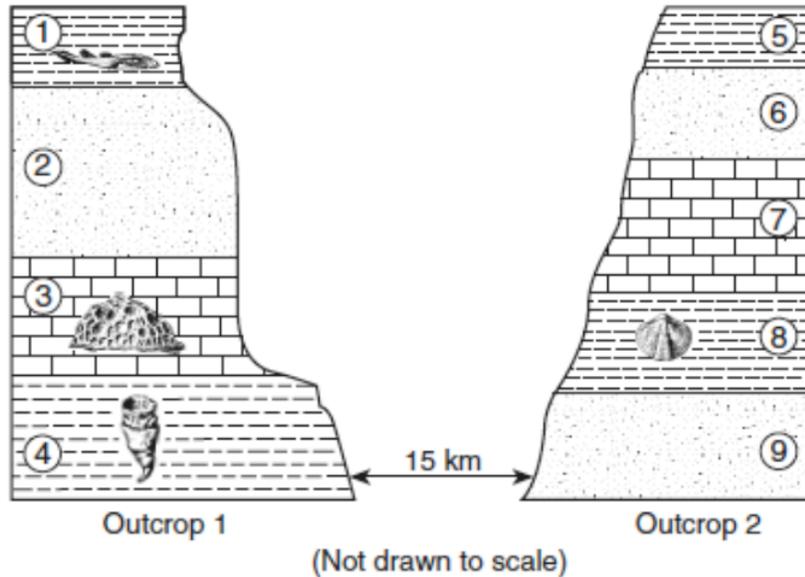
18. Which sequence of fossils shows the order in which the organisms appeared on Earth? Please select only one response.



19. Which of the following is a true statement about a population of a given species? Please select only one statement.

- A. All members of the population are identical.
- B. Variation among individuals in a population does not affect survival of the population.
- C. All individuals have the same likelihood of survival, independent of their characteristics.
- D. Individuals of a population vary in their characteristics.

Base your answer to Question 20 on the cross sections below, which represent two bedrock outcrops 15 kilometers apart.



20. When these rocks were deposited as sediments, this area was most likely

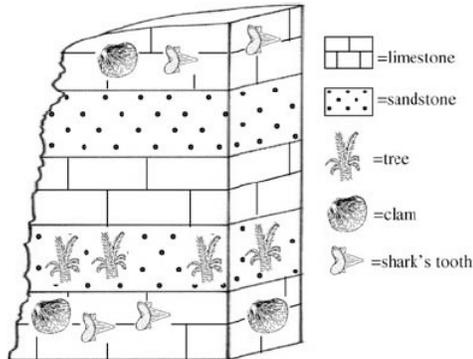
- A. under the ocean.
- B. a desert between high mountains.
- C. repeatedly covered by lava flows.
- D. glaciated several times.

21. Paleontologists discovered four different species of brachiopods in an outcrop of New York State bedrock. Observations suggest that the species are closely related even though they vary somewhat in shape and size. It is thought that they share a common ancestor.

Which factor could **not** have influenced these differences in brachiopod size and shape? Please select only one statement.

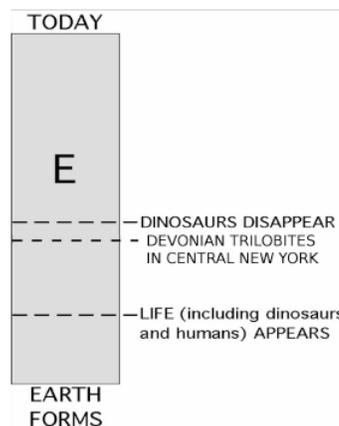
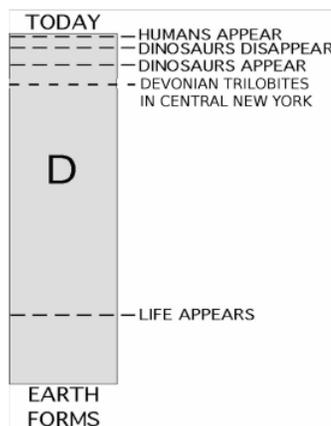
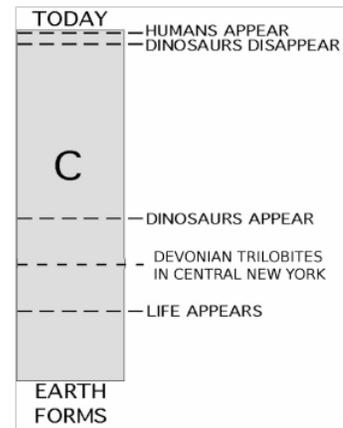
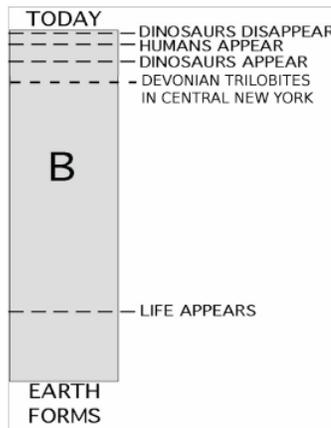
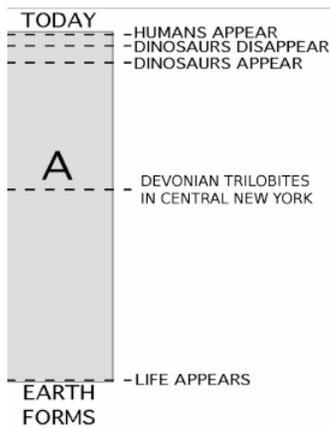
- A. Differences in the size and shape of the species from which each species evolved
- B. Variations in the way each species became adapted to niches in the local environment
- C. Differences in the goals each species has for its own evolution
- D. Variations among species and the effect of the environment on growth rates

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

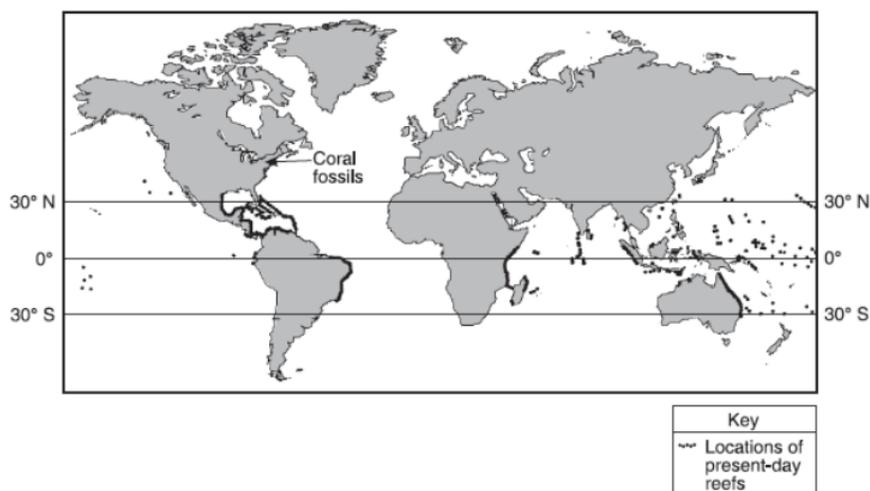


Based on this illustration, please describe what might have occurred through time at this site in order for these rock layers to have formed and for these fossils to have been preserved.

23. Which of the figures below do you think most closely represents changes in life on Earth over time? Please select only one response.



24. On the map below, the darkened areas represent locations where living coral reefs currently exist, in shallow marine environments. The arrow points to a location where large numbers of coral fossils have been found in Devonian-age bedrock in central and western New York State.



Devonian-age coral fossils found in some New York State bedrock are *not* located in the same general region that present-day corals are living. Based on what you know both about geology and marine organisms, which of the following statements help(s) explain this observation? Please select all statements that apply.

In the Devonian Period,

- A. New York State was closer to the equator.
- B. New York State had a colder climate.
- C. areas of New York were covered by warm seas.
- D. the average rainfall was much lower in New York than it is now.
- E. corals lived in land environments.
- F. New York State was once covered by a 3 km deep ocean.
- G. global sea level was higher.
- H. the Finger Lakes were bigger.

The E & A Center acknowledges and thanks contributors to this assessment. Items on this instrument were adapted and used with permission from the following sources:

- Question 1.** Graphic adapted from Project ICAN: <http://www.projectican.com/trickytracks.html> Item from Dr. Robert M. Ross, Paleontological Research Institute, & Daniel K. Capps, Cornell University, Fossil Finders Project 2008
- Question 2.** Graphic adapted from Project ICAN: <http://www.projectican.com/trickytracks.html> Item from Dr. Robert M. Ross, Paleontological Research Institute, & Daniel K. Capps, Cornell University, Fossil Finders Project 2008
- Question 3** Adapted from M.L. Rutledge & M. A. Warden (2000). Evolutionary Theory, the Nature of Science & High School Biology Teachers: Critical Relationships. *The American Biology Teacher*, 62 (1), 23-31.
- Question 4** Source material adapted from J. C. Libarkin (2008). *GCI Concept Inventory: GCI v.2.1.1*. Retrieved from: <https://www.msu.edu/~libarkin/gci.html>
- Question 5** Dr. Robert M. Ross, Paleontological Research Institute, & Daniel K. Capps, Cornell University, Fossil Finders Project 2009
- Question 6** Adapted from M.L. Rutledge & M. A. Warden (2000). Evolutionary Theory, the Nature of Science & High School Biology Teachers: Critical Relationships. *The American Biology Teacher*, 62 (1), 23-31.
- Question 7** Dr. Robert M. Ross, Paleontological Research Institute, & Daniel K. Capps, Cornell University, Fossil Finders Project 2009
- Question 8** Dr. Robert M. Ross, Paleontological Research Institute, & Daniel K. Capps, Cornell University, Fossil Finders Project 2009
- Question 9** Adapted from New York Regents Physical-Earth Science High School Examination, June 2007. Retrieved from: <http://www.nysedregents.org/testing/hsregents.html>
- Question 10** Source material adapted from J. Dodick & N. Orion (2003). Measuring Student Understanding of Geological Time. *Science Education*, 87 (5), 708-731.
- Question 11** Dr. Robert M. Ross, Paleontological Research Institute, & Daniel K. Capps, Cornell University, Fossil Finders Project 2009
- Question 12** Graphic and source material adapted from New York Regents Physical-Earth Science High School Examination, June 2006. Retrieved from: <http://www.nysedregents.org/testing/hsregents.html>
- Question 13** Source material adapted from New York Regents Living Environment High School Examination, January 2009. Retrieved from: <http://www.nysedregents.org/testing/hsregents.html>
- Question 14** Adapted from J. C. Libarkin (2008). *GCI Concept Inventory: GCI v.2.1.1*. Retrieved from: <https://www.msu.edu/~libarkin/gci.html>
- Question 15** Dr. Robert M. Ross, Paleontological Research Institute, & Daniel K. Capps, Cornell University, Fossil Finders Project 2009
- Question 16** Dr. Robert M. Ross, Paleontological Research Institute, & Daniel K. Capps, Cornell University, Fossil Finders Project 2009
- Question 17** Dr. Robert M. Ross, Paleontological Research Institute, & Daniel K. Capps, Cornell University, Fossil Finders Project 2009
- Question 18** Graphic and source material adapted from New York Regents Physical-Earth Science High School Examination, January 2008. Retrieved from: <http://www.nysedregents.org/testing/hsregents.html>
- Question 19** Source material adapted from D. L. Anderson, K. M. Fisher, & G. J. Norman. (2002). Development and Evaluation of the Conceptual Inventory of Natural Selection. *Journal of Research in Science Teaching*, 39 (10), 952-978. Item from Dr. Robert M. Ross, Paleontological Research Institute, & Daniel K. Capps, Cornell University, Fossil Finders Project 2008
- Question 20** Graphic and source material adapted from New York Regents Physical-Earth Science High School Examination, August 2008. Retrieved from: <http://www.nysedregents.org/testing/hsregents.html>
- Question 21** Source material adapted from New York Regents Living Environment High School Examination, January 2008. Retrieved from: <http://www.nysedregents.org/testing/hsregents.html>
- Question 22** Graphic and source material adapted from J. Dodick & N. Orion (2003). Measuring Student Understanding of Geological Time. *Science Education*, 87 (5), 708-731.
- Question 23** Graphic and source material adapted from J. C. Libarkin (2008). *GCI Concept Inventory: GCI v.2.1.1*. Retrieved from: <https://www.msu.edu/~libarkin/gci.html>
- Question 24** Graphic and source material adapted from New York Regents Physical-Earth Science High School Examination, June 2008. Retrieved from: <http://www.nysedregents.org/testing/hsregents.html>

Table A4.2. Views of inquiry and NOS questionnaire and scoring rubric

Question	1 Uninformed/Naive	1 Emerging	2 More Informed	3 Robust Understanding
<p>4.1) Current reform documents in science education call for teaching “science as inquiry.”</p> <p>What does this mean? [Refer to NRC, 2000]</p>	<p>Does not know and/or demonstrates naive conceptions, for example equates inquiry with hands-on work, questioning, discovering/exploration.</p>	<p>Where students answer questions by collecting data. Answer may indicate student or teacher direction.</p>	<p>Where students give priority to data, i.e. Involves manipulating, summarizing, interpreting, displaying data. Using data as evidence. Answer may indicate that teachers facilitate or guide students.</p>	<p>Where students use data as evidence in developing explanations/interpretations for a phenomenon. Answer may indicate understanding of a balance between student and teacher direction (e.g. “there are different levels of inquiry based teaching.”)</p>
<p>4.2) How might inquiry-based science teaching look in your classroom? [Refer to NRC, 2000]</p>	<p>Does not indicate any of the important abilities or understandings beyond asking questions</p>	<p>Recognizes one or two aspects (understandings or abilities)</p>	<p>Recognizes more than two aspects (understandings or abilities)</p>	<p>Recognizes more than one or two understandings of and abilities to do.</p>
<p>5) Do you think there are benefits to using inquiry-based science instruction? If so, what? If not, why not? [Refer to NRC, 2000]</p>	<p>Participant responds that there are no or few benefits <u>or</u> that challenges/obstacles outweigh benefits</p>	<p>Participant describes a few important, non-cognitive benefits such as engagement of students or cooperative learning</p>	<p>Very simple cognitive benefits like retention of knowledge, helping to remember. Engagement is likely seen as well (as in 1)</p>	<p>Participant describes cognitive benefits (such as increasing depth of content understanding, ownership (engagement, see 1 and 2) of learning, enhanced ability to transfer knowledge to novel situations, critical thinking)</p>

<p>6) How might classroom inquiry compare to scientific inquiry? [Refer to NRC, 2000]</p>	<p>No answer. Clearly does not understand or thinks the two are the same.</p>	<p>Begins to differentiate between the two but does not articulate a reasonable difference. Misconceptions.</p> <p>They both do similar things and begins to differentiate between the two</p>	<p>Recognizes the difference and may include some of the ideas in the robust category.</p> <p>Mentions ideas from the robust column (for example: might discuss that classroom inquiry is a guided version of SI, or talks about the sophistication), but does not get all the way there. Or might get all the way there, but includes some issues.</p>	<p>classroom is a construct that was developed to help model scientific inquiry in the classroom.</p> <p>(They are not the same. They have different goals. Mentions that scientific inquiry is more sophisticated and is attempting to discover new knowledge; Classroom inquiry relies on standards and is not necessarily as open, it focuses on student learning and about what science is, how scientists practice science, and the core science concepts)</p> <p>Talks about how classroom inquiry is guided by the teacher, generally not as rigorous or sophisticated (might only be partial, different material and time constraints)</p>
<p>7) How confident are you in your ability to teach science as inquiry? Please explain your answer.</p>	<p>unconfident</p>	<p>maybe – unconfident</p>	<p>maybe confident</p>	<p>Confident</p>
<p>8) Does science always involve doing experiments? Please explain your answer. [VNOS-C, Question 3]</p>	<p>Yes, it must. Maybe, maybe not (with no explanation)</p>	<p>Sometimes, but should also note other ways of doing science, for example through observational or descriptive studies (but offers no example of such or explanation). Includes misconceptions.</p>	<p>Sometimes/often there are other ways of doing science, for example, observational or descriptive studies. Offers an example or an explanation.</p>	<p>The methods used in a scientific investigation depend on the question asked (for example, “some questions/hypotheses cannot be tested directly.”)</p>

9) What is the scientific method? Do all scientists use the scientific method? Explain. [Combined VOSI, Question 6 with VNOS-C, Question 2]	I do not know, scientific method must be used, or <i>good</i> science must follow the scientific method.	Indicates that the scientific method is more flexible than commonly believed/taught: not all of the steps are always necessary, specific order of steps is not important.	Indicates that there are multiple methods of science (beyond the understanding as in 1). For example, not all science is experimental, or some scientific investigations are observational or descriptive.	Indicates that there are multiple methods of scientific investigation (as in 2) both within scientific discipline and across different scientific disciplines and/or science depends on questions
10) What does the word data mean in science? Is data the same as or different from evidence? Please explain your answer using examples. [VOSI, Question 4]	Data are collected information. Evidence is different – evidence is something left behind (like trace evidence) and/or Data and evidence are the same thing – there is no difference between how these two terms are used in science	Data and evidence are the same thing but the words are used differently in science (cannot explain) Data and evidence are different degrees of the same thing (cannot explain)	Data are <u>amassed</u> to produce evidence that supports or refutes a claim.	Data are <u>interpreted</u> to provide evidence that supports or refutes a claim
11) Are observations the same as or different from inferences? Please explain your answer using examples.	No response or misconceptions on both observation and inference.	Accurately defines one term but not the other	Accurately defines one term, and closely approximates the second.	Accurately defines both terms without misconceptions <i>(Observations can be made with only the five senses; Inferences involve a decision or interpretation being made about something you observe.)</i>
12.1) What is a scientific theory? [VNOS-C, Question 6]	Demonstrates major misconceptions about what a theory. e.g. not proven “theories develop into laws (once they are proven correct)” or “ a theory is just a hunch.”, it’s a	Theories are based on evidence, they are something we believe to be true	Theories describe or explain, based on evidence	Explanatory framework, based on evidence (observed patterns), can generalize and predict (basically similar to 2, but beyond)

	big idea, a guess			
12.2) After scientists have developed a scientific 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. [VNOS-C, Question 6]	No they don't change or demonstrates major misconceptions other than theory-law distinction .	Theories can/do change because of new information, data, discoveries or technology. However, makes no connection between data and evidence. May fall into this category because of theory-law issue, because someone with this issue really can't be more informed.	Theories can change when new evidence weighs in against it (repeated testing). Answer must convey the importance of weighing evidence and includes no major misconceptions.	Theory change requires the weighing of evidence, but theories are unlikely or difficult to change and answer includes no major misconceptions.
13) Is there a difference between a scientific theory and a scientific law? Please explain your answer. [VNOS-C, Question 5]	A theory becomes a law when it is proven. Or theories change (are tentative) but laws do not (laws are proven).	Knows that at least the idea of a hierarchical relationship between theory and law is incorrect. But the rest of the answer demonstrates lack of knowledge or misconceptions	"Theories explain and laws describe." No further elaboration – no way to distinguish belief from parroting statements from the PD.	"In general, laws are descriptive statements of relationships among observable phenomena. Boyle's law, which relates the pressure of a gas to its volume at a constant temperature, is a case in point. Theories, by contrast, are inferred explanations for observable phenomena or regularities in those phenomena. For example, the kinetic molecular theory serves to explain Boyle's law." (VNOS 2002) ("Theories and laws are different kinds of knowledge and one does not become the other. Theories are as legitimate a product of science as laws.")

<p>14) Is there a role for creativity and/or imagination in scientific investigations? If yes, then at which stages of the investigations do you believe that scientists use their imagination and creativity: planning and design; data collection; after data collection? Provide examples if appropriate. If no, please explain why not and provide an example. [VNOS-C, Question 8]</p>	<p>Science is objective, there is no creativity in what scientists do. or Science is subjective.</p>	<p>Indicates that creativity is important in some combination of the following: developing questions, experimental design, collecting and/or displaying data.</p>	<p>Indicates that creativity is important interpretation, analysis and or explanation but offers no explanation or example other than in terms of trouble-shooting</p>	<p>Indicates that creativity is important in all stages of scientific investigation and provides explanations or an example pertaining to interpretation, explanation, or the construction of an argument. and/or or takes the social/constructivist perspective of scientific knowledge: scientific knowledge is socially constructed and culturally embedded (e.g. “human component”).</p>
<p>15) Is the work of scientists influenced by society? Please explain your answer using an example. <i>Socially and culturally embedded</i> [VNOS-C, Question 10]</p>	<p>No outside influences on science other than personal attributes (for example, personal religious beliefs)</p>	<p>People belong to a society and their personal beliefs can be influenced by that society/culture</p>	<p>Social norms limit what gets funded AND/OR socio-political issues guide funding (little or no explanation or example</p>	<p>Science effects society and is affected by society.</p>
<p>16.1) It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a</p>	<p>Does not know how to answer this question (e.g. “good question!”). or Responds that the events in question happened too long ago for us to really know, or were too violent/chaotic to be understandable. These theories are just opinions.</p>	<p>Indicates that different people have different interpretations of events or different perspectives, but provides no further explanation other than different backgrounds or bias. May include misconceptions.</p>	<p>Indicates that different people (different scientists) have different interpretations of events or data, or different perspectives of such. Also provides a reasonable example or further explains. Includes no major misconceptions.</p>	<p>Indicates that different interpretations or perspectives arise because of socio/cultural factors (e.g. education, experiences) or because of creativity (or the idea of tentatively). Includes no major misconceptions. Scientists weigh</p>

<p>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.</p> <p>How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions? [VNOS-C, Question 8]</p>	<p>or The data are inconclusive, there is not enough data.</p>		<p>Scientists use subjectivity and creativity to form conclusions</p>	<p>evidence/judge arguments and employ subjectivity/creativity. May also offer a social-constructivist explanation involving acceptance of the scientific community.</p>
<p>16.2) Is it possible for two different scientists to perform the same scientific procedures and reach different conclusions? Please explain your answer. [VNOS-C, Question 8]</p>	<p>Responses to this question are used to further categorize respondent on the above continuum for understanding the Theory Laden NOS.</p>			
<p>17) Explain the process of how a paleontologist might...How might you investigate how organisms or climate changed throughout the geologic past in central New York? [Refer to Chinn & Malhotra, 2001- i.e. rationale for verbal developing an investigation as a means to determine understanding of science]</p>	<p>No idea or, no mention of comparison. Might talk about data (e.g. rock type of fossils, but don't talk about what to do with it). Just mentions uniformitarianism, but no mention of data. Too vague.</p>	<p><i>Collecting data and comparing data (layers or sites) or comparing data across times (uniformitarianism). No "how" or "Why" in their answer. No explanation of how the evidence could be used to understand climate change.</i></p> <p><i>Just collecting data. Here are some of the kinds of data one could collect...</i></p> <p><i>(former answer: One or two of</i></p>	<p><i>Collects and compares as in emerging, and provides an explicit connection between organism or rock type and climate at different times (for example:)</i></p> <p><i>(former answers: Collecting data and explaining what the different kinds of data could indicate.</i></p> <p><i>Has all three ideas from robust: types of data to</i></p>	<p><i>Answer goes beyond collecting data and connecting it to the explanation. For example, ALSO indicates connecting to previous research, knows that both numbers and types of fossils are important kinds of data, describes several different rock types and what they indicate, includes several different sources of data and describes how they connect to different explanations).</i></p>

		<p>the ideas from robust with, explanation is absent or weak.</p> <p>Some form of data and the idea of using samples from from different times. Or just one good element from the 3 category)</p>	<p>collect, comparing layers, and an explanation of how to use data, but provides weak explanation.</p> <p>Or has 2/3 of these with a strong explanation.</p> <p><i>Makes an explicit connection between organism or rock type and climate at different times</i></p>	<p>(former answer: Lists reasonable types of data to collect (rock type or sediment type, sedimentary structures, organisms, or chemical information in the rock), comparing layers at a site and across sites, and gives a valid explanation of how to use data to answer the question)</p>
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References

- Abd-El-Khalick, F., Bell, R.L., & Lederman, N.G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, 82(4), 417-436.
- Abd-El-Khalick, F., & BouJaoude, S. (1997). An exploratory study of the knowledge base for science teaching. *Journal of Research in Science Teaching*, 34(7), 673-699.
- Adams, P.E., & Krockover, G.H. (1997). Beginning science teacher cognition and its origins in the pre-service science teacher program. *Journal of Research in Science Teaching*, 43, 633-653.
- Akerson, V.L., & Donnelly, L.A. (2008). Relationships among learner characteristics and preservice elementary teachers. views of nature of science. *Journal of Elementary Science Education*, 20(1), 45-58.
- American Association for the Advancement of Sciences. (1989). *Project 2061: Science for all Americans*. New York: Oxford University Press.
- American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.
- Anderson, R.D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, 13(1), 1-12.
- Birman, B.F., Desimone, L., Porter, A.C., & Garet, M.S. (2000). Designing professional development that works. *Educational Leadership*, 57(8), 28.

- Campbell, D.T., & Stanley, J.C. (1963). *Experimental and quasi-experimental designs for research*. Boston: Houghton Mifflin.
- Capps, D.K., & Crawford, B.A. (2010). Teachers translating inquiry-based curriculum to the classroom following a professional development: A pilot study. Paper presented at the Annual Conference of the National Association for Research on Science Teaching, Philadelphia, PA.
- Capps, D.K., & Crawford, B.A. (2011). *Inquiry-based instruction in science classrooms: Is it happening?* Paper presented at the Annual Conference of the National Association for Research on Science Teaching, Orlando, FL.
- Capps, D.K., Crawford, B.A., & Constan, M.A. (in press). A review of the empirical literature on professional development: Alignment with best practices and a critique of the findings. *Journal of Science Teacher Education*.
- Capps, D.K., & Crawford, B.A. (in preparation). *Teaching science as inquiry: Documenting the journey*.
- Carey, R.L., & Stauss, N.G. (1970). An analysis of experienced science teachers' understanding of the nature of science. *School Science and Mathematics*, 70(5), 366-376.
- Carey, S., & Smith, D. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist*, 28(3), 235-251.
- Chinn, C.A., & Malhotra, B.A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, 86(2), 175-218.

- Cochran-Smith, M., & Lytle, S.L. (1999). Relationships of Knowledge and Practice: Teacher Learning in Communities. *Review of Research in Education*, 24, 249-305.
- Committee on Science and Mathematics Teacher Preparation. (2001). *Educating teachers of science, mathematics, and technology: New practices for the new millennium*. Washington, DC: National Academy Press.
- Crawford, B.A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, 37(9), 916-937.
- Crawford, B.A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, 44(4), 613-642.
- Creswell, J.W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). Los Angeles: Sage.
- Darling-Hammond, L., & McLaughlin, M.W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan*, 76(8), 597.
- Desimone, L.M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher*, 38(3), 181-199.
- Dewey, J. (1933). *How we think: A restatement of the relation of reflective thinking to the educative process*. Boston: DC Heath and Company.
- Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23(7), 5-12.
- Elbaz, F. (1981). The teacher's "practical knowledge": Report of a case study. *Curriculum Inquiry*, 11(1), 43-71.

- Fenstermacher, G.D. (1994). The Knower and the Known: The Nature of Knowledge in Research on Teaching. *Review of Research in Education*, 20, 3-56.
- Fulton, K., & Britton, T. (2011). *STEM teachers in professional learning communities: From good teachers to great teaching*. (Washington, DC: National Commission on Teaching and America's Future).
http://www.wested.org/online_pubs/1098-executive-summary.pdf
- Garet, M.S., Porter, A.C., Desimone, L., Birman, B.F., & Yoon, K.S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, 38(4), 915-945.
- Geddis, A. (1993). Transforming subject matter knowledge: The role of pedagogical content knowledge in learning to reflect on teaching. *International Journal of Science Education*, 15, 673-683.
- Geier, R., Blumenfeld, P.C., Marx, R.W., Krajcik, J.S., Fishman, B., Soloway, E., & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. *Journal of Research in Science Teaching*, 45(8), 922-939.
- Hmelo-Silver, C.E., Duncan, R.G., & Chinn, C.A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, 42(2), 99 - 107.
- Hodson, D. (1992). In search of a meaningful relationship: An exploration of some issues relating to integration in science and science education. *International Journal of Science Education*, 14, 541-562.

- Kennedy, M. (1998). *Form and substance in in-service teacher education*. Arlington, VA: National Science Foundation.
- Lederman, N.G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, 29(4), 331-359.
- Lederman, N.G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching*, 36(8), 916-929.
- Lederman, N.G., Abd-El-Khalick, F., Bell, R.L., & Schwartz, R.S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, 39(6), 497-521.
- Loucks-Horsley S., Love N., Stiles K.E., Mundry, S., & P.W., H. (2003). *Designing Professional Development for Teachers of Science and Mathematics* (2nd ed.). Thousand Oaks, CA: Corwin Press.
- Loughran, J.J. (2002). Effective reflective practice. *Journal of Teacher Education*, 53(1), 33-43.
- Luft, J.A. (1999). Assessing science teachers as they implement inquiry lessons: The extended inquiry observational rubric. *Science Educator*, 8(1), 9-18.
- Luft, J.A. (2001). Changing inquiry practices and beliefs: the impact of an inquiry-based professional development programme on beginning and experienced secondary science teachers. *International Journal of Science Education*, 23(5), 517-534.

- Magnusson, S., Krajcik, J., & Borko, H. (2002). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. Lederman (Eds.), *Examining Pedagogical Content Knowledge* (Vol. 6, pp. 95-132): Springer Netherlands.
- Minner, D.D., Levy, A.J., & Century, J. (2010). Inquiry-based science instruction - what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, 47(4), 474-496.
- National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.
- National Research Council. (2000). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.
- Pajares, M.F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research*, 62(3), 307-332.
- Penuel, W.R., Fishman, B.J., Yamaguchi, R., & Gallagher, L.P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, 44(4), 921-958.
- Putnam, R.T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher*, 29(1), 4-15.
- Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. In J. Sikula (Ed.), *Handbook of research on teacher education*. New York: Simon & Schuster.
- Schön, D.A. (1983). *The reflective practitioner*. London: Temple Smith.

- Schwartz, R.S., Lederman, N.G., & Crawford, B.A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, 88(4), 610-645.
- Shepardson, D.P., & Harbor, J. (2004). ENVISION: the effectiveness of a dual-level professional development model for changing teacher practice. *Environmental Education Research*, 10(4), 471 - 492.
- Shymansky, J.A., Kyle, W.C., & Alport, J.M. (1983). The effect of new science curricula on student performance. *Journal of Research in Science Teaching*, 20(5), 387-404.
- van Driel, J.H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching*, 38(2), 137-158.
- Wayne, A.J., Yoon, K. S., Zhu, P., Cronen, S., & Garet, M.S. (2008). Experimenting with teacher professional development: Motives and methods. *Educational Researcher*, 37(8), 469-479.

CHAPTER 5

SUMMARY AND CONCLUSIONS

In chapter two, I presented a critical review of the literature on inquiry professional development (PD). Results from the review revealed that few empirical studies (17) related specifically to science-inquiry PD programs have actually been published in major peer-reviewed journals in science education. Existing studies generally aligned with recommended features of effective PD with a few notable exceptions, including: supporting teachers in developing inquiry-based lesson plans, providing authentic inquiry experiences, and focusing on science content for teachers. The studies included in the review reported on a range of findings, but no study connected participation in inquiry-based PD with all the desired outcomes of teacher PD: enhanced teacher knowledge, change in beliefs and practice, and enhanced student achievement. This review highlights the need for future studies that will help build a chain of evidence between teacher learning and student learning.

In the third chapter of this dissertation I investigated the teaching practice, and views of inquiry and nature of science (NOS), of a group of highly-motivated teachers prior to participating in an inquiry-based PD program. Findings indicated that even some of the best teachers held limited views of inquiry-based instruction and NOS. Moreover, the majority of teachers used primarily teacher-centered instructional practices. Elements of inquiry including *abilities*, *understandings*, and *essential features* were observed in less than half of the classrooms. The study provided

empirical evidence for the claim that teachers are not teaching science in accordance with reform-based ideas. Further, it highlights the critical need for an agreed upon definition of inquiry-based instruction and rigorous PD to support teachers in learning about inquiry, NOS, and reform-based teaching.

Chapter four examined the science content knowledge and views of inquiry and NOS of a group of participant and comparison teachers before and after an inquiry-based PD experience. Findings indicated that short-term, yet intensive PD that engaged teachers in an authentic investigation effectively enhanced teachers' subject matter knowledge and views of inquiry and NOS. Moreover, it appeared that teachers who made reflective comments showed greater gains in their knowledge and views. Results from this study suggest that active reflection may be important in enhancing teacher knowledge and might be a significant intermediary step in changing one's classroom practice. This study highlights the need for high-quality PD that extends beyond the initial PD work session and supports teachers in reflecting on their experiences and practice.

Future research connected with the Fossil Finders program will focus on documenting teacher classroom practice and student learning. One study will describe what happens as teachers enact an inquiry-based curriculum in their classroom. For example, how do they translate the PD experience into practice, and is there evidence of transference into other lessons? Another study will document student learning using a combination of pre and post-assessment data, classroom observations, and student interviews. The overall aim of these studies will be to build a chain of evidence between teacher learning and student learning.