

Chapter 3

Moving the Essence of Inquiry into the Classroom: Engaging Teachers and Students in Authentic Science

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3.1 Introduction

How can teachers help children understand what science is, what science is not, and develop images of how scientists think and work? How can we create science classrooms where children use observations as evidence and creatively try to understand the world? My long-time career interests involve trying to figure out how we can change the way science is taught in most classrooms across the United States. First and foremost, I am a teacher. As a former public school science teacher, I taught life science and biology, physical science, chemistry, and physics to children aged 12–18 in the United States for over 16 years. For the past 15 years, I have worked with preservice and in-service science teachers in designing classrooms that provide children an opportunity to gain an interest in science, use science inquiry, and learn about nature of science. My passion is to engage children in actively understanding what science is, not by trying to memorize the massive amount of facts in science textbooks but through investigation, by grappling with data, and in becoming critical thinkers. Ultimately, I would like all children to be motivated to learn about science and how to do science and to develop into lifelong learners of science. The main question driving this chapter is how can we move *science as inquiry* into the science classroom?

Decades ago, inquiry had been posed as an effective method of engaging students in real-world experiences (Dewey 1938). Although the U.S. reform documents (American Association of the Advancement of Science [AAAS] 1989, 1993; National Research Council [NRC] 1996, 2000) emphasize inquiry as a central strategy

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for teaching science, the reality is that most teachers do not use inquiry-based instruction in their classrooms. Further, there is little empirical evidence of effective ways to support teachers in understanding the nature of scientific inquiry and how to implement inquiry in science classrooms.

My view of teaching science as inquiry, at its most basic level, involves helping children to find answers to questions using logic and evidence. Inquiry involves going beyond the simple asking of questions, to trying to figure out how to make sense of data to answer a scientifically based question. Aligned with guidelines in education reform documents in the United States, the learner asks and answers scientifically oriented questions about the natural world, gives priority to evidence in responding to questions, comes up with explanations using data as evidence, connects explanations to scientific knowledge, and communicates and justifies explanations (NRC 2000). Similar to what a scientist does, the student figures out something by himself/herself, *with the guidance of the teacher*, by making sense of observations, the text in a book, the images on a computer screen, or the data gathered during an investigation. At the heart of inquiry is the learner herself, *grappling with data* and making sense of some event or phenomenon in a social environment.

Inquiry-based teaching is a complex and sophisticated way of teaching that requires the teacher to have an adequate understanding of scientific inquiry and the nature of science and inquiry-based teaching approaches (Crawford 2000, 2007). The kinds of inquiry conducted in classrooms should reflect a range of scientific work beyond that of experiments, including using observational methods and historical reconstruction (Duschl et al. 2007; Millar 1989). This kind of teaching requires significant professional development and support. Many teachers do not have adequate preparation in science to create a successful inquiry-based environment (Krajcik et al. 2000), or they simply may not understand what inquiry is (Anderson 2002), or not have beliefs and views that support this kind of teaching (Gallagher 1991; Lederman 1992; Luft 2001). The problem is more acute at the elementary and middle school levels, where teachers generally have little or no formal science training and lack familiarity with the fundamentals of scientific inquiry (Loucks-Horsley et al. 2003).

3.2 Theoretical Framework

The theoretical framework guiding the design of my research and assertions offered in this chapter include two main areas, social constructivism and authenticity.

3.2.1 *Social-Constructivist Perspectives of Learning*

This view of learning aligns with the recent framework and assessments in the PISA project (see Bybee et al. 2009) in which context is important. I view learning from a social-constructivist perspective, taking the position that knowledge is developed

in the context of personal experiences in collaboration with others (Driver 1989; Driver et al. 1994; Vygotsky 1978). In a process of grappling with data to make sense of it and through negotiation of ideas with peers and experts in a social context, the learner gains an individual and internalized understanding of science.

3.2.2 Authenticity

The *construct of authenticity* is an important theoretical construct that underpins my views of teaching science as inquiry in classrooms. Authenticity relates to classroom practices similar to those in which scientists engage, including epistemological and reasoning aspects (Chinn and Malholtra 2002). Authenticity in the science classroom demonstrates or replicates the kinds of work scientists do and is relevant to students (Braund and Reiss 2006; Dewey 1938; Hodson 1998; Roth 1995). Just moving a scientist's science into classrooms without some modification of the science content and methods to match the developmental level of students is not appropriate. The authentic aspect of the science classroom-based instruction includes transforming the traditional static classroom instruction to include a more dynamic interaction between the teacher and the learner, as suggested by Rahm et al. (2003). The importance of the time, place, and situation related to the authentic nature of a science-learning environment is highlighted by educational learning theorists (Brown et al. 1989).

An example of authenticity in school science is provided by Rosebery et al. (1989) in the Cheche Konnen project, a study that provided some evidence for the importance of connecting inquiry to the lives of diverse children. The learning environment was transformed from traditional worksheet-driven instruction to authentic inquiry for these Haitian middle-level students when they investigated the drinking water in their school and came up with their own questions. Important considerations include the following: what are the goals of science instruction? For whom is science authentic? What kinds of developmentally and culturally appropriate experiences are feasible in classroom situations? How can teachers address aspects of the nature of scientific inquiry and attend to the developmental and cultural needs of learners?

3.3 Building upon a Research Agenda Focused on Inquiry

The centerpiece of my research agenda is understanding and developing viable ways to support teachers and students in using and understanding inquiry. Together with colleagues, I have carried out a series of empirical studies over the last several years, investigating how learners, in a range of settings and levels, gain understandings of the processes, nature, and subject matter of science through inquiry.

3.3.1 *The Nature of the Studies*

These studies include (1) *A Middle School Community of Learners*, a qualitative study of my own middle-level students engaged in open-ended projects designed by the students in collaboration with experts outside the classroom (Crawford et al. 1999); (2) *The Community Slough Project*, a case study of an experienced high school ecology teacher who engaged his students in an authentic investigation of a local river slough with university experts (Crawford 2000); (3) *High School Students' Authentic Summer*, a study investigating high school science students participating in a summer-long research internship at a university and the influence of the experiences on their ideas about scientific inquiry and nature of science (Bell et al. 2003); (4) *The Authentic Research Seminar for Preservice Teachers*, a study of adults in a graduate-level science teacher education course that integrated an authentic research experience with a campus-based, theory-driven seminar, rich in opportunities for discussion and reflection (Schwartz et al. 2004); and (5) *Teaching Methods and Modeling*, a study of undergraduate college students preparing to teach secondary science, as they designed investigations of real-world phenomena, then built and tested models of scientific phenomena using modeling software (Crawford and Cullin 2004).

3.3.2 *Assertions from These Studies*

Drawing from these studies, there is growing evidence for a proposed model of inquiry learning and teaching science in classrooms incorporating three components: active investigation, authenticity, and reflection. A summary of some key assertions based on prior work includes:

- Authenticity, in its various forms, can provide a valuable context for reflection on aspects of the nature of scientific inquiry (i.e., Schwartz et al. 2004; Schwartz and Crawford 2004).
- Authentic contexts are those that support the learner in making sense of naturally occurring events and constructing compelling explanations that justify the time, resources, and effort needed to set inquiry into action (Crawford et al. 2005).
- Authentic science in classrooms enables students to engage in investigations that are meaningful to them (e.g., Crawford et al. 1999; Crawford 2000; Krajcik et al. 1998).
- Guidance by the classroom teacher to facilitate students in collaborating with others is critical (Crawford 2000; Crawford et al. 1999).
- Authority of the teacher may impede, rather than support, the process of negotiating ideas, and the willingness of the teacher to shift authority to students is critical for success (Crawford et al. 1999).

In our research team's recent efforts to understand how to effectively support teachers and facilitate students in learning to do scientific inquiry, through inquiry,

and *about* inquiry, we designed a multiyear project that combines an authentic scientific investigation, innovative inquiry resources and tools, an interactive data-based website, and teacher professional development. The basic idea is to immerse teachers (as learners) and their students in an authentic science investigation. In this case, the investigation involves classroom students helping scientists learn about past environments. The learning *of* science in this project includes core concepts related to geology and evolutionary theory (Catley et al. 2004). Teachers involve their students in contributing data to the authentic scientific investigation and in learning about multidisciplinary concepts such as uniformitarianism, superposition, diversity, structure-function, deep time, environments, change over time, finding patterns in data, and aspects of nature of science.

In this chapter, I will present some of our preliminary findings from a project designed to provide authentic experiences for teachers and students and to help teachers bring their inquiry experiences into their classrooms. I will present evidence of the kinds of things teachers learned and how teachers began to translate their knowledge of inquiry to their classrooms and, in turn, how students were engaged in authentic science experiences and what students learned about scientific inquiry and key science concepts.

3.4 The Fossil Finders Project: Research to Practice

In January 2008, researchers from the Cornell University Department of Education and the Paleontological Research Institution (PRI) in Ithaca, New York, collaborated to actively support teachers and children in learning about science inquiry and concepts related to evolutionary theory. The *Fossil Finders* project strives to bridge research to practice by engaging teachers and children in classrooms carrying out an authentic investigation of Devonian fossils. The goals of the project include helping children and teachers to understand how scientists use evidence to build theory, enhance abilities to do inquiry, and stimulate interest in paleontology, biology, and geology in target demographics (females, low socioeconomic status [SES] and English language learners [ELL] students). Ultimately, the *Fossil Finders* project aims to provide a viable national model for creating effective partnerships between science museums, science education researchers, and teachers and children in classrooms. These partnerships could be effective in supporting teachers in providing inquiry-based, authentic science to their students. The theoretical framework guiding our work is that learning is associated with meaningful activities. This view is embodied in the constructs of social constructivism, situated cognition, and cognitive apprenticeships (Brown et al. 1989; Lave and Wenger 1991).

In the *Fossil Finders* project, children from two grade spans (5th/6th and 7th/9th) receive samples of rock (i.e., samples of shale from an Upstate New York State outcrop) shipped to their classrooms. Teachers help children look for the fossils in the rock, identify the fossils they find, and measure the fossils and fossil fragments and note other characteristics (see Appendix for a sample lesson). Teachers and

Table 3.1 Roles in creating an authentic inquiry-based science classroom

Collaborators	Various roles
Scientists	Provide research question Develop protocols for analyzing the fossil data Use student-contributed data to develop scientific explanations Provide tools and materials Develop explanations (reconstruct the geologic past of central New York)
Science education researchers	Provide inquiry teaching strategies Explicit nature of science support Curriculum development Liaison between scientists and teachers
Teachers	Engage with scientists (in studying past environments) Facilitate students in gathering and analyzing data (identifying and measuring fossils, analyzing aggregate data) Help students understand key science concepts and NOS Provide feedback on lessons and pedagogy Change agents in classrooms
Students	Identify fossils in rock samples Enter their class data into an online database Analyze data Work with their peers Help scientists develop explanations (reconstruct the geologic past of central New York) Ask their own questions

students use an interactive website and submit their own data to an emerging database. A key focus is on classrooms with a high proportion of underrepresented groups of children (whose race and gender are not well represented in the sciences). The idea of authenticity is front and center in the instructional materials. For example, teachers are encouraged to say to their students, “We will be the first ones to collect this (fossil) data. Nobody else has looked at these samples and knows what will be found! We will use this data to learn about science, share with scientists and other classes, and perhaps answer some questions of our own or questions posed by other classes.”

The *Fossil Finders* project provides a context for students to learn about how the Earth has changed throughout time. Students begin to piece together an understanding that New York State (in the northeastern part of the United States) once had very different environmental conditions from today. Teachers help students to understand that the area where people live now was not always as it is today. In fact, instead of fresh water lakes and farmlands, there is evidence of a warm shallow sea. This understanding of a past environment serves to lay the groundwork to develop more sophisticated understandings of environmental change.

Teachers, scientists, science education researchers, and students all collaborate to answer a driving question and enter data on a website (www.fossilfinders.org). See Table 3.1 for the various roles of collaborators.

3.5 Supporting Teachers Through Professional Development

To support teachers in understanding inquiry, we planned and carried out a summer institute in Ithaca, New York. We used the research on professional development programs (i.e., Loucks-Horsley et al. 2003) and our own research on inquiry-based teaching (Crawford 2000, 2007) to inform the design of our teacher professional development. In particular, Loucks-Horsley et al. (2003) describe strategies that include immersion in inquiry into science and mathematics and immersion into the world of scientists. In the *Fossil Finders* project, the focus of our designed professional development involves an authentic scientific setting conducive to translation to a science classroom, combined with modeling an inquiry approach with explicit connections to aspects of nature of science. The centerpiece of the *Fossil Finders* project is the authentic paleontological investigation examining how sea life responded to changes in the environment during the Devonian Period in central New York.

During the first summer of the project, ten New York State teachers participated in the 5½-day summer institute. During this time, we involved teachers in four field trips; lessons and discussion in a Geology classroom of how to find, identify, and measure fossils; how to translate ideas of inquiry and nature of science into classrooms; sessions of the various versions of inquiry in the national science education standards; a tour of the Museum of the Earth in Ithaca, NY, highlighted by a behind-the-scenes look at the work of paleontologists and the world class PRI fossil collections; and evening discussions of ELL strategies and a session on how to deal with controversial issues of teaching about evolution.

3.6 Collecting Multiple Forms of Data

To track changes in teachers' and students' views of inquiry, NOS, and evolutionary concepts and of teachers' practice in their classrooms, we used a mixed methods approach consisting of a qualitative, interpretive approach informed by Creswell (1998) and Miles and Huberman (1994), and quantitative data based on pre-post questionnaires (Woodruff et al. 2011). The data on teacher change included multiple sources. First, we administered the pre-post teacher questionnaire to all ten teachers on the first day of the summer institute and immediately following the institute. The pretest was administered the afternoon the teachers arrived on campus. The pre- and posttests were identical. Teachers completed the pretest using laptop computers provided to them the first day and the final day of the summer institute. We asked teachers not to use outside sources in responding to questions. Second, we conducted a semi-structured postinstitute teacher interview. Third, we obtained videotape data of all ten teachers in their classrooms, taken prior to the summer institute as a baseline for inquiry teaching. Fourth, our team videotaped all teachers in their classrooms as they carried out the *Fossil Finders* inquiry-based instruction. Fifth, we used the

teacher application materials to determine initial views and motivation for participating in the project. We triangulated analyses of the multiple data sources.

To assess children's views of inquiry and nature of science and knowledge of science concepts, the research team and external evaluation team identified and developed student instruments that specifically addressed the goals and content of the *Fossil Finders* project. Several valid and reliable items were identified and used, with permission, to construct instruments for the project. Additional items were developed by *Fossil Finders* project personnel in order to assess content for which no appropriate existing, valid items were available. The *Fossil Finders Student Questionnaire Form E* was developed for elementary students (Grades 5 and 6) and included two subscales and six questions collecting demographic data. The first subscale, "Content Form E (elementary level)," addressed *Fossil Finders* science content knowledge and included 14 multiple-choice items. The second, "VNOS Form E," subscale was adapted with permission from the *Views of Nature of Science Elementary School Version (VNOS-E)* (Lederman and Lederman 2005) and included six open-response items. Form S (secondary level) and Form E of the student questionnaire can be available from the author upon request.

3.7 Teachers' Changes in Views and Knowledge and Practice

In our preliminary data analyses, we detected positive changes in all ten teachers' views of inquiry, NOS, and of earth and evolutionary concepts, pre to post. Following the *Fossil Finders* professional development experience, teachers demonstrated a more informed understanding of some aspects of NOS and science inquiry, including how scientists reach different conclusions from the same evidence, and the importance of data and its relationship to evidence. For example, one 5th-grade teacher, WK developed a more informed understanding of the nature of scientific inquiry, in addition to targeted science concepts. There is evidence that at the beginning of the professional development, WK held the naïve idea that there is a *single* scientific method – in other words, scientists always follow one particular set of steps (a misconception depicted in many science textbooks). Evidence of this view is the response on the prequestionnaire. WK wrote, "Yes, I think it does need to follow these steps to ensure an accurate result." Through her experiences in the summer institute, WK developed a more informed understanding that scientists use multiple methods, and they selected a particular research method, depending on the type of research question investigated. Regarding inquiry, many teachers, at first, demonstrated a "confused" view of inquiry and equated inquiry with simply, "hands-on teaching." For example, a teacher initially stated, "inquiry teaching is hands-on work, that includes questioning and discovering (VM)." The problem with this view is that teachers may miss the important aspect of inquiry-based teaching in which a teacher moves students from simply collecting data, to using data as evidence in developing explanations, and connecting their explanations to scientific views.

3.8 Teachers Translating Their Views to Their Classrooms

Moving beyond enhancing teachers' knowledge, our research team is interested in the question, *what is the evidence of teachers translating their knowledge and views of inquiry to their own classrooms?* Following the summer institute, we visited teachers' classrooms and videotaped several lessons associated with the *Fossil Finders* curriculum. Representative examples of how students engaged in essential features of inquiry in their science classrooms during the *Fossil Finders* project appear in Table 3.2.

To assess changes in teaching practice, we videotaped a lesson suggested by each teacher earlier that spring. We used this lesson as a baseline to detect changes, if any, in their teaching approaches, by comparing with postvideos. Preliminary analyses of pre-post lessons revealed that all teachers demonstrated at least some positive movement toward using more reformed-based ways of teaching, including using more than one or two features of inquiry-based instruction (see Capps and Crawford 2010). Given the complexity of teaching, we understand the limitations of using one videotaped lesson (pre) as a means to assess a teacher's practice. Videotapes of single lessons cannot capture all the nuances of teaching. However, we also analyzed teacher responses to written questions and conversations to triangulate our data and attempted to portray the most accurate representation of these teachers' view of teaching science.

Table 3.2 Essential features of inquiry in the *Fossil Finders* classroom (Adapted from NRC 2000)

Feature (abbreviation)	Description of feature	Example in classroom
<i>SQ</i> scientific question	Learner engages in answering a <i>scientifically oriented question</i>	Learner asked to help answer, how did sea life respond to the environment in New York State, nearly 400 million years ago?
<i>DE</i> data as evidence	Learners <i>gathers (or is given) data to use as evidence</i> for answering the question	Learner identifies and measures brachiopods, clams, trilobites, and other fossils he or she finds in shale samples
<i>EE</i> evidence-based explanations	Learner grapples with and analyzes data to develop <i>evidenced-based explanations</i> and answers by looking for patterns and drawing conclusions	Learner makes graphs of kinds and size of fossils, enters his or her data into an online database, uses data as evidence, using fossils as clues to what the area was like nearly 400 million years ago
<i>SE</i> scientific explanations	Learner connects the <i>explanations</i> with those explanations and concepts developed by the <i>scientific community</i>	Learners connects her explanations of the past environment with those of paleontologists and geologists
<i>CD</i> communicating and defending	Learner communicates, justifies, and <i>defends explanations</i>	Learners discuss class findings among peers and post a report on the project <i>Fossil Finders</i> website in the student-scientists area

In observing teachers enacting the *Fossil Finders* curriculum and investigation, there were many instances of teachers delving deeper into the use of evidence with their students. Prior to the PD, one fifth-grade teacher, Kristen, involved her students in “hands-on” activities; however, the use of essential features of inquiry was limited to that of “asking students questions.” For many teachers, we observed them asking primarily closed-ended, “yes” or “no” questions to their students. Many questions were not scientifically oriented. After the professional development, there was evidence that teachers made a point to ask students to think about the difference between observations and inferences. Specifically, Kristen began to ask more scientifically oriented questions. She began to press her students to consider the use of data as evidence for their explanations.

3.8.1 Kristen’s Teaching Practice: Pre

Prior to the professional development, Kristen’s teaching was characterized as *hands-on and issue-based instruction, with an emphasis on vocabulary words*. In her application to the program, Kristen described a unit on recycling. Her main objective was to instill lifelong stewardship. She explained that “The Kickoff Lesson” was presented by a guest speaker from our community – Greta Garbage who visited our class and spoke about the significance of recycling and the consequences of landfills. The lesson included several read aloud mini-lessons, which led to small group discussions and independent reflection. What Kristen called “experiments” in her unit were indeed interesting, but not aligned with our view of inquiry-based teaching. Classroom videotape data showed Kristen asking her students questions; however, these questions were generally fact-based questions, such as “What are the differences between reptiles and amphibians,” or questions that can be answered by looking up information in textbooks: “Can amphibians breathe water? That’s the question we need to answer.”

Analysis of Kristen’s prevideo showed her 5th-grade students working at various lab stations. Students moved from one station to the next, after completing tasks. At the stations, students made observations of dragonfly wings under a microscope, looked at reptiles (live turtles), completed a worksheet on photosynthesis, and a worksheet on amphibians. Students worked quietly in groups of three. In the video, one can hear an aide speaking Spanish with a student in the background. At the photosynthesis station, Kristen asked students to write down definitions and copy the chemical equation for photosynthesis. However, the teacher did not probe students for their understanding of photosynthesis or encourage them to ask questions at the various stations.

In this prelesson, although students were busy “doing things,” there was limited evidence of the essential features of inquiry in this classroom. The teacher did begin her instruction by asking questions of her students. Beyond the initial questions, the teacher did not scaffold her students in answering these questions (unless she expected them to go to outside resources, but this was not discussed in the video).

3.8.2 *Kristen's Teaching Practice: Post*

Videotaped classroom observations following the *Fossil Finders* professional development showed evidence of Kristen involving her students in inquiry beyond that of asking them closed-ended questions. In the lesson description below, Kristen helps students to distinguish between observations and inferences.

MV_093008_TrickyTracks.wmv

Teacher puts Tricky Tracks transparency slide on overhead projector. Students write in their journal responses to the prompt, "What do I see?"

Students make Journal entry; included some illustration, and students discussed with peers what they observed.

-8:46 – Teacher Prompted Group Discussion

Tell the size or nature of the organism?

Teacher asks students to recount their inferences. How many of you thought there were two types of animals? Why? Are you making inferences about size of animal based on size of footprints? Are there two individuals?

-10:39 – Connecting observations to stories. Past experiences – walking in the snow.

Journal Entry: Sequence of events explaining what is observed on the slide.

Following class discussion, teacher asks, if they are dinosaurs, then what were the dinosaurs doing? Teacher (class consensus?) speaks of the tracks as representing dinosaur tracks.

She asks, why are the dinosaurs fighting? For food?

If they are fighting over food, what did environment look like? What did these dinosaurs eat?

In the lesson segment above, Kristen, through a series of questions and follow-up prompts, facilitates her students in developing explanations based on evidence, an essential feature of scientific inquiry. She also scaffolds her students in distinguishing between observations and inferences, a tenet of nature of science. One of the misconceptions that can get in the way of children understanding evolutionary theory is the lack of understanding how scientists develop a theory. A scientific theory is a way to explain a phenomenon and is not just an educated guess, but built on a great deal of evidence over time.

These preliminary findings from the first year of the *Fossil Finders* project provide evidence of improvement in teachers' views of science, understandings of nature of science, and understandings of some evolutionary concepts, and abilities to use inquiry-based approaches in their teaching practice following the professional development. We cannot claim cause and effect, but it is likely teachers' growth and apparent changes in practice are associated with their professional development experiences and use of the *Fossil Finders* curricular materials. We are beginning to find more evidence of these changes in teacher practice, and our current studies reveal more robust findings.

3.9 Impact on Student Learning of Scientific Inquiry

Ultimately, we are interested in the impact of inquiry-based instruction on student learning of science concepts, principles, and nature of science. Specifically, do students understand more about what science is, from engaging in the *Fossil Finders*

Table 3.3 Form E (elementary) respondent student gender and race/ethnicity

Race/ethnicity	Participant			Comparison		
	Female	Male	Total	Female	Male	Total
African-American	16	17	33	26	21	47
Native American/Alaskan Native	1	2	3	3	1	4
Asian or Pacific Islander	1	2	3	0	1	1
Hispanic/Latino(a)	3	0	3	22	10	32
White (not Hispanic/Latino)(a)	11	16	27	17	25	42
Other	10	7	17	8	13	21
<i>Total</i>	42	44	86	76	71	147

inquiry-based instruction? To assess the effectiveness of the Pilot *Fossil Finders* materials, we constructed student assessments (pre and post). The developed instruments have three scales: content science knowledge items, NOS items, and inquiry items. We administered these assessments to students in our Pilot teachers' classrooms, at the beginning of the school year 2008 and near the end of the school year Spring 2009. Additionally, we asked our teachers to select a comparison teacher (not involved in the project, but teaching similar classes in the same grade level and in the same school) to provide a control group of students. The comparison teacher administered the pre- and posttests to classes similar to those of the *Fossil Finders* teachers.

In total, 86 fifth-grade students participated in the first year of the *Fossil Finders* program, representing a wide range of race/ethnicity (see Table 3.3 for displays of respondent race/ethnicity and gender for participant and comparison groups). As shown in Table 3.3, most of the Form E (elementary) prequestionnaire respondents indicated either African-American (32% of participant; 38% of comparison) or White (29% of participant; 31% of comparison) as their race/ethnicity. Male and female respondents were relatively evenly distributed for each group.

Significant differences were found between the *Fossil Finders* elementary students' and comparison students' postcontent knowledge scores and understanding of certain aspects of the nature of science and inquiry (see Woodruff et al. 2011). In an effort to provide a control in the study, the students in the comparison classrooms had science lessons during the same time period as the children in the project classrooms, and these lessons related to similar subject matter. But we did not have specific information on the exact lessons used in each comparison classroom, only that the subject matter was similar. While comparison group students' performance improved on the content knowledge subscale, no improvement was seen in their understanding of inquiry and NOS. Further, ANOVA results suggest that differences in gains between *Fossil Finders* students and comparison students were attributable to exposure to *Fossil Finders* materials. See Fig. 3.1 for a display of students' pre- and post-Rasch mean scores of change in views of nature of science by *Fossil Finders* participation. A summary of the preliminary, first-year data analyses appears below:

- *Fossil Finders* elementary student mean scores improved on all but one item on the *subject matter knowledge assessment*, with 4 (of 13) items demonstrating

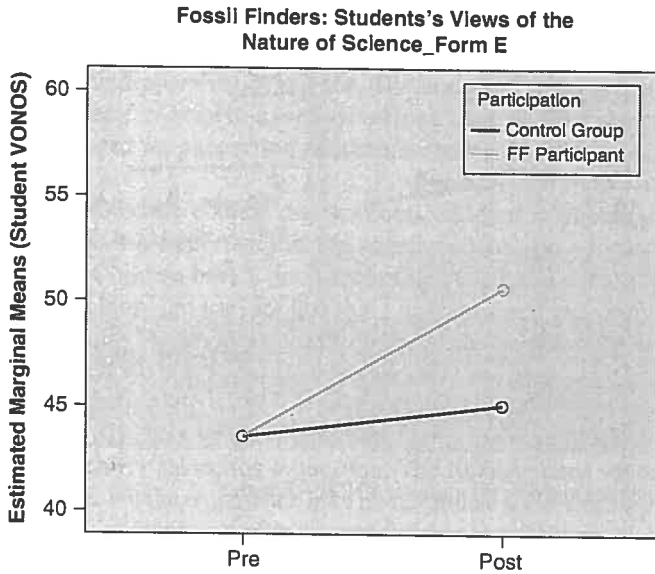


Fig. 3.1 Students' pre and post Rasch mean scores on "VNOS Form E" by Fossil Finders participation

statistically significant gains. Students demonstrated a better understanding of important Earth science and evolutionary concepts, including (a) impact of environmental change on organisms, (b) the law of superposition, and (c) fossil-forming processes.

- *Fossil Finders* elementary student mean scores improved on 5 of 7 items measuring *knowledge of the nature of science*. Students demonstrated a more informed understanding of two critical concepts, including (a) the tentative nature of science and (b) the use of creativity and imagination in scientific investigations. Interestingly, students were not able to articulate an informed definition of science in response to the question, "What is science?" either before or after exposure to the *Fossil Finders* materials.

We had evidence that elementary-level students in the *Fossil Finders* project classrooms gained a more informed understanding of one aspect of nature of science, that of scientists' use of creativity and imagination. In answering the question, why do scientists disagree about why and how dinosaurs died (*Q5*), refer to Fig. 3.2 for a display of a one student's matched pre- and postquestionnaire responses to this item and see examples used in the scoring of the pre- and postresponses. In the pre-response, this student views science as basically a collection of facts. In the post-response, this student indicates that in this kind of science (paleontology), one can never really know "because they don't have a time machine to go back in time."

Pre	Post
<p>8. (a) Do you think scientists use their imaginations when they do their work?</p> <p>Yes <input type="radio"/> No <input checked="" type="radio"/></p> <p>(b) If No, explain why?</p> <p>because science is usually based on facts</p>	<p>8. (a) Do you think scientists use their imaginations when they do their work?</p> <p>Yes <input checked="" type="radio"/> No <input type="radio"/></p> <p>(b) If No, explain why?</p> <p>Because they don't have a time machine to go back 4 billion years.</p>
<p>"They disagree because all facts have different scenarios [sic] unless you have all the facts so they might not have all the facts" (Scored as a 1)</p>	<p>"They disagree because they are different people." (Scored as a 3)</p>

Fig. 3.2 Sample pre and post responses to VNOS – E Item 5

3.10 Conclusion

In this section, I return to the main question posed in this chapter, *how can we move science as inquiry into the classroom?* Preliminary findings from our recent project add support to the hypothesis, if there is an intense focus on *authenticity* during teacher professional development, this focus can strengthen a teacher's abilities to carry out inquiry-based instruction and facilitate students in learning science. This finding aligns with social constructivist and situated cognition theories of learning (Brown et al. 1989; Lave and Wenger 1991).

As we continue to work collaboratively with teachers and scientists to further develop and refine the Fossil Finders inquiry-based curriculum, we are working toward developing a model of an inquiry-based community of learners in a science classroom (Crawford et al. 2009). Our emerging model gives teachers specific roles; teachers not acting as passive participants in a professional development experience, but as active inquirers and agents of change. When our teachers are given opportunity to participate in authentic science, they demonstrate greater confidence in enacting inquiry-based instruction in their classrooms; their enthusiasm, in turn, increases, and we see evidence of motivated and engaged students in their classrooms.

Moving students toward an understanding and appreciation of the enterprise of science can enable the individual, regardless of race, culture, gender, and social class, to continue to build on his or her previous knowledge of science throughout life. In this way, a person may better participate as a citizen in understanding controversial and difficult issues, such as factors that may contribute to global climate change. The method of moving all learners toward a deeper understanding of science, first and foremost, positions students in active participation in authentic inquiry in education settings. When children engage in real-world, authentic

investigations, connect their prior knowledge to new learning experiences, and are supported by a knowledgeable other in learning the cultural tools of science, they will gain a deeper understanding of science. The important point is that the teacher needs to hold, himself or herself, a well-developed view of what science is and of the pedagogy required for supporting children in their own thinking about science as inquiry.

In creating an authentic context that scaffolds children in pursuing answers to scientific questions, it is important that the questions have some importance to the life of the learner. Children have a good sense that “made-up” scientific questions, designed only for classroom use, are just that – prefabricated and decontextualized exercises that strive to teach scientific facts and procedures, with little regard for the nature of the learner. Authenticity to the learner does not necessarily mean that the topic is of cutting-edge importance to research scientists. The authentic science investigation may likely be embedded in a local community problem requiring a systematic approach for answering a question. The findings may not revolutionize the scientific world, but the experience *may* revolutionize the learner’s thinking. An ultimate goal in science education is for the learner to reflect on his or her own learning, and it is this component of learning that will position the student in sustained curiosity and a lifelong quest for understanding science.

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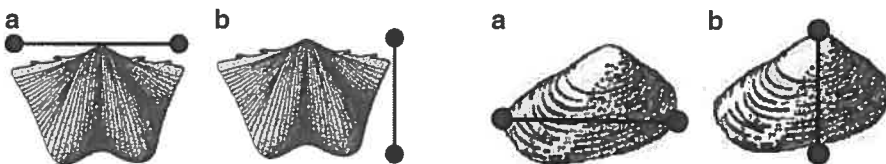
Appendix

Lesson Description

This 5-day paleontological investigation engages students in authentic scientific inquiry. Through this investigation, there are many opportunities to discuss evolutionary, geological, and nature of science concepts. Students will learn about collecting, compiling, and interpreting data related to a population of fossils. After collecting the data, students will then enter their data into an online database and analyze and interpret the data they collected. The online database can also be used to share data with other classes and scientists and look for trends in the data beyond one’s own class.

An Excerpt of the Lesson

- *Say:* We will be the first ones to collect this data. Nobody else has looked at these samples and knows what will be found! We will use this data to learn about science, share with scientists and other classes, and perhaps answer some questions of our own or questions posed by other classes.
- Explain how to fill out each sheet.
- For *brachiopods* and *bivalves* (sheets 1 and 2) students will measure in millimeters (mm's) in the *A* direction and *B* direction indicated on the handouts and PowerPoint slides (see example below). They will also indicate the color of the fossil and fragmentation.



- For all other organisms (sheets 3 and 4) the students need to first record what type of fossil they are measuring. Next they will measure length, width, color and fragmentation (see examples on the PowerPoint).

Data Analysis

Explain

The explanation portion of the investigation should take about 1–2 class periods but could take more if your students are engaged. The class should have already entered their data into the database. *Elementary grades* should focus on producing graphs from the first two data plots: *Relative Abundance of Organism within a Sample and Distribution of Organism Sizes*.

Within a sample of the database; however, feel free to use the other graphs as well. At the end of this section, elementary students will have recreated what proportions of different kinds of organisms would have lived in the Devonian Sea in the area they were studying. From this, they can begin to infer what the sea may have looked like based on the data they collected from their fossils.

(*Relative Abundance of Organisms within a Sample*) – If students have access to computers (or if there is a projector in the classroom), ask students to click on View Reports and create a graph showing relative abundance using the database. Have students use the graph they produce to consider how the *data they collected gives clues to what the area was like nearly 400 million years ago?* Students should select their sample from the drop-down list and click the graph button in the bottom-right hand corner of the box. Based on what they found in the rocks, what do they think the area where their rocks formed looked like during the Devonian Period (360 and 415 million of years ago)? What might it have been like if they snorkeled through the area? *What would the Devonian Sea have looked like ~400 million years ago? How do they know?*

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