SCIENCE TEACHER EDUCATION

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No Silver Bullet for Inquiry: Making Sense of Teacher Change Following an Inquiry-Based Research Experience for Teachers

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ABSTRACT: Inquiry is seen as central to the reform of science teaching and learning, but few teachers have experience with scientific inquiry and thus possess very naïve conceptions of it. One promising form of professional development, research experiences for teachers (RETs), allows teachers to experience scientific inquiry in the hopes that these experiences will then translate to inquiry in the classroom. As intuitively pleasing as these programs are, scant evidence documents their effectiveness. For this study, four secondary science

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teachers were followed back to their classrooms following a 6-week, marine ecology RET. The research employed qualitative and quantitative data collection to answer these questions: What were the teachers' initial conceptions and enactment of classroom inquiry, and how did they change after the RET?; How did changes in the nature and use of questions highlight changes in inquiry enactment?; and How were the teachers' changes linked to the RET and are there changes that cannot be explained by the RET experience? Teachers who entered the program with more sophisticated, theory-based understanding of teaching and learning were more apt to understand inquiry as a model and to use classroom-based inquiry throughout their teaching following the program. Implications for professional development are discussed. *Sci Ed* **93:**322–360, 2009

INTRODUCTION

Inquiry-based teaching is strongly recommended by the American Association for the Advancement of Science ([AAAS], 1993) and the National Research Council ([NRC], 1996, 2000) as a strategy to develop deeper student understanding of science to apply to the everyday world. These reform documents clearly recommend that teachers should be spending more time using inquiry-based instructional strategies in problem-solving contexts, and less time in didactic presentations of facts (Southerland, Gess-Newsome, & Johnston, 2003). Bybee (2004, p. 9) suggests, "Inquiry as a teaching strategy should capture that spirit of scientific investigation and the development of knowledge about the natural world."

Yet recent studies suggest that most teachers have very little experience with inquiry in a formal scientific sense, and thus possess very naïve and informal conceptions of inquiry and inquiry in the classroom (Anderson, 2007; Windschitl, 2004). Anderson (2003) asserts that teachers' lack of experiences with authentic scientific inquiry experiences gives them static conceptions of science, what he describes as an "authoritative picture of how the world works" (p. 9). In her work with 10 secondary science teachers, Blanchard (2006) found teachers' conceptions of inquiry to be defined in applied, practical ways embedded in their classroom practices and described in terms of what the teacher was doing or what the student was doing. Recent work by Lotter, Harwood, and Bonner (2007) suggests that teachers' core teaching conceptions (views of science, the purpose of education, students, and effective teaching practices) influence their receptivity to inquiry-based teaching. In their study, Lotter et al. found that viewing science as a set of facts to be amassed worked against teachers' acceptance of inquiry. Instead, teachers' goals of encouraging independent thought and expanding students' ability supported their receptivity to inquiry.

The work of Rahm, Miller, Hartley, and Moore (2003) suggests that the vast differences between the work of teachers and the work of scientists make it impractical for the scientific models as practiced by scientists to be replicated in classrooms. Rahm et al. assert "school science is best perceived as a form of science practice that by its nature will always be different from what real scientists do" (p. 739). However, in *Inquiry and the National Science Education Standards*, a critical follow-up analysis of inquiry in the *Standards*, the NRC states, "For students to understand inquiry and learn to use it in science, their teachers need to be well versed in inquiry and inquiry-based methods" (2000, p. 87). How then are science educators to bridge the chasm between teachers' views of an authoritative science and the strong recommendation they embrace inquiry in the classroom?

One avenue is involving teachers in professional development, described as a fundamentally important way to give teachers a vision of inquiry and to help them to implement inquiry-based science teaching in their own classrooms (e.g., Blanchard, 2006; Borko, 2004; Luft, 2001). For more than 20 years, the National Science Foundation (NSF) has funded many such professional development efforts in the form of research experiences for teachers (RETs). The fundamental premise of most RETs is that teachers “who have experience in the practice of science, and in the use of science in the ‘real world,’ can better communicate the concepts and value of science to their students” (Dubner et al., 2001, p. 3.6.3). In most RET programs, teachers engage in scientific research at the “elbows” of scientists so that they experience all the stages of inquiry as a learner, with the expectation that this experience may translate into greater fluency in enacting inquiry in the classroom (e.g., Dresner & Worley, 2006; Rahm, Miller, Hartley, & Moore, 2003). Typically, immersion in these intensive experiences, coupled with appropriate follow-up activities during the school year, expands teachers’ professional skills and networks, and is thought to improve their students’ science learning.

The appeal of RETs and other related professional development experiences is not firmly grounded in evidence demonstrating the success of these programs to foster inquiry in the classroom (Dubner et al., 2001; Frechtling, Sharp, Carey, & Westat, 1995; Whitehouse, Breit, McCloskey, Ketelhut, & Dede, 2006). Indeed, the ways in which teachers actually implement inquiry in the classroom following professional development have not been adequately studied (Crawford, 2000; Marx et al., 2004; Yerrick, 2000).

THEORETICAL FRAMEWORK

Teacher Knowledge and Beliefs

As we work to understand the influence of RETs on classroom practice of inquiry, Crawford’s (2000) work is illuminating. She reminds us of the complexity of teachers’ roles in inquiry-based classrooms, and suggests we “need to turn our attention on how to best support teachers in embracing the essence of inquiry” (p. 935). In her recent work, Crawford (2007) argues that teachers’ “complex set of personal beliefs about teaching and of science” influence teaching science as inquiry (p. 613), echoing the efforts of Woodbury and Gess-Newsome (2002). The work of Harwood, Hansen, and Lotter (2005) and Lotter et al. (2007) support the notion that teachers’ beliefs influence how they teach as well as how they respond to professional development. Anderson (2002) explains,

> It is common to talk about barriers or obstacles that must be overcome for teachers to acquire an inquiry approach to teaching. . . but much of the difficulty is internal to the teacher, including beliefs and values related to students, teaching, and the purposes of education. . . . (p. 7)

Lotter et al. (2007) point out the importance of both pre- and postdata on the teachers who are involved in professional development if we are to understand the changes in teachers’ conceptions and enactment of inquiry that are engendered through such programs.

Developmental Model

An underlying assumption of our research is that RETs function by supporting teacher change and development. Building on teacher education research that addresses the role of teachers’ conceptions and beliefs and their influence on their teaching practice (Gess-Newsome, Southerland, Johnston, & Woodbury, 2003; Windschitl, 2004), we focus on teacher conceptions and beliefs through a developmental lens, using Kegan’s (1994) psychological developmental hierarchy. In Kegan’s developmental model, individuals evolve in the way they organize experiences as they mature. In this developmental process, experiences are not replaced, but are “subsumed into more complex systems of mind” (p. 9).

Consciousness (The way one knows) —lead to→ How one understands the world (worldviews/values/beliefs) —lead to→ Feelings —lead to→ Behavior

Figure 1. Adaptation of Kegan's (1994) developmental hierarchy.

Kegan's (1994) model of development describes change at the level of consciousness, changing the way we know. When a person changes, he does not just change "what he knows, but the *way* he knows. . . for his mind to be different. . . to alter his consciousness, to change his mind" (p. 17). In Kegan's psychological model (Figure 1), changing behavior depends upon whether we want to change (our feelings), how we see the world (which includes our beliefs and values), and changing the way we know (our consciousness). [Note: Figure 1 was developed by Blanchard (2006) based on Kegan's (1994) text. It appears here with slight edits.] One of the difficulties Kegan describes in educators working with adult learners is that we are "not merely asking them to take on new skills. . . [but] asking them to change the whole way they understand themselves, their world, and the relationship between the two" (p. 275).

In the process of teaching, teachers often think about what they are doing as they do it, what Dewey (1910) and Schön (1988) call "reflection-in action." Reflective thinking requires that an individual is able to stand apart from himself and abstract himself to observe what he is doing, and also requires that the teacher desires to do so (Kegan, 1994). Research suggests that reflection on practice is a critical component of teacher reform (Luft, 2001; Roehrig & Luft, 2004). Borko (2004) asserts that reflection using records of classroom practice are "powerful tools for facilitating teacher change" (p. 7).

The developmental aspect of Kegan's (1994) model is that teachers may select to change what they are doing by examining their underlying feelings, and supporting this, their beliefs and values, and ultimately, at the most fundamental level, changing the way they know. In Kegan's model, when teachers select to change, and these changes are lasting, the teacher has developed. Kegan terms these changes, in which the person redefines and reorganizes her perspective on herself and her relationships, as "transformative" (p. 294).

The Role of Questions in Science Teaching

So how ought we to go about looking for changes in science teachers' actions, a first step to investigating change at underlying levels? One starting point is to begin with thinking about what science is, and what tends to go on in science classrooms. Science is a body of knowledge and also a process of knowledge generation (Carlsen, 1992). Through classroom language and activity, teachers shape the ways in which students interact with science and learn about what is known and the processes of science (Lemke, 1990). Bartholomew, Osborne, and Ratcliffe (2004) describe the use of teachers' questions as a way teachers relay well-established knowledge about science.

According to Carlsen (1992), classroom discourse not only conveys what is known about science, but also models science as a process. This classroom discourse is usually controlled by the teacher, who may funnel the classroom talk into predictable patterns so the teacher stays in control, an authoritarian model of teaching (Lemke, 1990). In Lemke's "triadic dialogue," the teacher asks a question, the student responds, and the teacher evaluates the response, a prevalent form of questioning in secondary science classrooms. Carlsen (1992) describes how teachers who are teaching unfamiliar subject matter often close down conversations to "constrain science to an exploration of the known" (p. 15). He cautions, "If student questioning is curtailed, for example, then science is distorted" (p. 15). Indeed, an authoritarian model of teaching, with the teacher controlling the classroom discourse, is at odds with national reform goals in science teaching. For instance, the National Science Education Standards want students to

> have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, asking questions, planning and conducting investigations. . . .thinking critically and logically about relationships between evidence and explanations. (NRC, 1996, p. 11)

In light of these goals, one might expect that during laboratory work the role of teachers' questions might shift to be more open ended. But Edwards and Mercer (1987, as cited in van Zee, 2000) describe that teachers often retain tight control over student conversations even in classrooms with active student investigations (as cited in van Zee, 2000).

In her research on inquiry-based instruction, van Zee (2000) examines college students who were engaged in inquiry-based discussions, which she defines as students generating comments and questions about a topic without much intervention of the teacher. She describes that by practicing "distributed authority" and "quietness," she promoted more inquiry-based discussions. This resonates with studies by Fagan, Hassler, and Szabo (1981) and Swift and Gooding (1983), who explain that increasing Wait Time I and II increased the cognitive level of the teacher questions (as cited in Carlsen, 1991). Carlsen (1991) describes that student participation increases when teachers relinquish control and do not judge student responses.

According to Huitt (2004), coding the classroom questions using a revised Bloom's taxonomy provides valuable insight into student learning. Carlsen (1991) explains that when low-level teacher questions dominate, students are discouraged from asking questions. Conversely, research demonstrates that students remember more when they have learned to respond to higher cognitive level questions because more elaboration is required (Huitt, 2004). Therefore, assessing the taxonomic level and the number of both student and teacher questions are methods to ascertain the depth of the students' engagement in the material, and therefore, indirectly, the quality of the science lesson. In van Zee's (2000) study, students who participated in inquiry-generated discussions engaged in all of the processes of the National Science Education Standards except for connecting their learning to what was already known. She describes their interactions as displaying "many aspects of critical and logical thinking such as proposing explanations, predictions, and interpretations; identifying assumptions; and considering alternative explanations and interpretations" (p. 132).

Questions and questioning are important in science and in science teaching; they also were an integral component of the RET program whose inquiry model is the basis for the experiences of the teachers studied in this paper. Therefore, changes in classroom questions from pre- to postprogram were particularly relevant to assess the impact of the program on the changes in teachers' inquiry-based instruction. As with van Zee and Minstrell's (1997) work, we were interested in all utterances that had the grammatical form of a question and were captured in conversation with the teacher. As a unifying characteristic of classroom instruction, analyzing the use of questions allowed for a comparison of lessons that varied substantially pre- to postprogram, such as a lesson that was laboratory based compared to one that was not. Using question analysis, Blanchard and Davis (2006) found that the type and cognitive level of teachers' questions flowed from the stage of inquiry in which they engaged, rather than explicit attempts on the part of the teacher to ask certain kinds of questions, regardless of the school context. Paired with the science teacher inquiry rubric (STIR; Bodzin & Beerer, 2003), which notes more concrete features of inquiry (who developed the question, who planned the investigation), question analysis offers insight into the cognitive engagement of the students, from pre- to postprogram (see Methods for a full description of STIR).

RESEARCH QUESTIONS

Given how little is known about the influence of RETs to change teachers' conceptions of inquiry or fostering inquiry in the classroom, the goal of this research was to describe the change of four secondary teachers who engaged in an RET program and understand the factors influencing these changes. In this particular RET, the role of questions and questioning was key to the inquiry modeled. Thus, the questions guiding this research were

1. What were the teachers' initial conceptions of inquiry, and how did they change following the RET?
2. How did teachers enact inquiry before the program, and how did the enactment change after the program?
3. What changes were there in the nature and use of questions from pre- to postprogram, and how do these highlight changes in enactment?
4. How were teachers' changes linked to the RET, and were there changes that cannot be explained by the RET experience?

Professional Development Context: Marine Ecology for Teachers Program Description

The RET in this study was called the Marine Ecology for Teachers Program (MET), a professional development program funded by NSF (Granger & Herrnkind, 1999) and offered through a major university in the southeast (ESI-9819431). This program was designed to facilitate teachers' understanding about inquiry both as a method for scientific research *and* as a strategy for teaching science. The resulting program engaged teachers in meaningful scientific research *and* a concurrent in-depth study of the inquiry modeled by the program. Through emphasis on this intersection of knowledge about doing inquiry and knowledge about teaching through inquiry, teachers were supported in developing the necessary pedagogical content knowledge (PCK) for teaching through inquiry (Gess-Newsome & Lederman, 1999; Shulman, 1986). In this case, PCK refers to teachers' ability to understand the model of inquiry in which they engaged well enough to translate that model to a lesson of their own design and appropriate to their classrooms. The MET design reflects the research that suggests that research experience offered in tandem with reflection on the teaching of inquiry is essential for teachers to internalize aspects of inquiry (Luft, 2001; Roehrig & Luft, 2004; Schön, 1987).

To gain entry to the program, each teacher was required to videotape an inquiry-based lesson and complete a questionnaire describing her/his conceptions of inquiry. The directions for the videotape were purposefully vague in an attempt to have teachers submit what they currently considered "inquiry." Thus, the range of lessons submitted by teachers was disparate, and some of them were not laboratory based. No other criteria were required, and admission was "first come, first served" until all 24 slots were filled by a mixture of elementary, middle, and secondary teachers who taught some science.

In the MET, two scientists and two master teachers worked alongside teachers in scientific research and pedagogy sessions throughout the 6-week program at a biological field station situated along the coast. One of the premises underpinning the research portion of this model was that teachers need to experience scientific inquiry from its inception, from initial observations through development of a hypothesis, experimentation, and findings. The approach used by the MET emphasized scientific activity authentic not only to science (Chinn & Malhotra, 2002) but also to the participants (Abrams, Southerland, & Silva, 2007). In that way it differed from the traditional RET model, in which a teacher joins a research project already in progress in the laboratory of a scientist, and so the activity may be authentic to science but not authentic to the participating teacher (e.g., Barnes, Hodge, Parker, & Koroly, 2006).

Teachers in this RET began by walking along the shore of the marsh and making observations, which was novel to most of the participants and thus promoted a large number of questions. Next, teachers' questions were elicited in a whole-group session, and one of the questions, "Why did the periwinkle snail climb up the marsh grass?," was homed in on by the lead scientists, as this question lent itself well to many subquestions. For instance, Was it to keep from drowning? Was it to escape predators? Was it to avoid the waves? Was it to obtain food? This ability of the broad question of what the periwinkle snails were doing on the marsh grass to branch out into all sorts of testable questions, and the plentiful number of them for investigations, led the MET scientists to preselect this broad question as the one they "funneled" teachers toward, after the teachers had proposed the question as one from a number generated from their observations. Once the lead scientist focused on this broad question, each team of teachers developed subquestions about the snails' behavior and, with the help of two scientists and science educators, worked to develop the general subquestion into a testable question.

Next, teams worked to develop a research methodology that would answer the question they were asking. This step required in-depth question sessions, thinking, and talking with staff scientists. For instance, when a group investigating whether changes in salinity affected snails climbing the marsh grass proposed, "We are going to put the snails under water for ten minutes and see how many of them survive," the staff scientist asked, "How will this test the effect of salinity on the snail?" Given that this was a new skill for many of the teachers, it was very difficult for them to determine how to test their hypotheses. A "tool talk" by the scientists as the teachers were developing experimental designs demonstrated equipment and techniques that might be useful, such as ways that snail shells could be superglued to dental floss and tethered at intervals in the water, or how to use a refractometer to gauge water salinity. Once a team decided on research protocols, they needed to try out these methods and refine them, again very focused on whether the data they collected would indeed answer the question they were trying to answer. During the data collection phase, teams would sometimes realize the weaknesses of their experimental design, and some revised their methods or materials, collecting additional data.

As teams finished data collection, teachers wrote up analyses and developed Power Point presentations, then gave these talks to the entire group. Indeed, most teams' findings generated more new questions than answers to questions. By listening to the presentation of findings of all of the groups, it was possible for teachers to glean a fuller understanding of the factors influencing the movement of periwinkle snails on marsh grass (e.g., to escape predation), and to eliminate some of the hypotheses (e.g., to avoid drowning). Scientists at the session modeled questions for the presenters, and gently pointed out weaknesses in the design of the study, or data interpretations, thus modeling the process of how science is presented at conferences. The teachers' second study was developed by each team according to more individual interests, for instance, *Does the surface area of a sponge make it a better nursery than that of an anemone?*

There was an intensive focus on questions during MET: stimulation of questions; development of testable questions; a research design that would seek to answer the questions asked; and the resultant additional questions prompted by field observations and data analysis. This focus is encapsulated by a statement by the lead scientist on the project,

> What is science but to be able to generate questions? I am a research scientist. I don't really know much science. I mean, I am not a science authority. I just know how to ask questions.

In the example of the team who investigated the surface area of the sponge versus that of the anemone, teachers collected multiple organisms from a set area, and then painstakingly separated out visible organisms with tweezers and used hand lenses and dissecting microscopes to try, with the aid of some classification materials, to count and classify groups of organisms on the anemones versus the sponges. This was aided in part by the scientists, who helped with unknown organisms, some of which were in larval stages.

Concurrent with the marine science research experience, the teachers engaged in an *inquiry* on *inquiry-based instruction* directed by two master teachers. Teachers were asked to systematically reflect on the inquiry process and the pedagogical features of the inquiry modeled by the lead scientist. For example, in the first week, after the teachers had walked on the shore, then generated questions as a group, then worked to home their research question in their team, they were sent to a whole-group session with a science educator who was an expert at reflective practice. In this session, teachers were asked to "put on their teacher hats" and analyze what had happened during their time with the scientists. Asked to focus on the first phase of the RET, in which the teachers had walked on the shore and talked about all the new things they were seeing, and asking questions, teachers wrote out all of the steps that they as learners had taken, and all of the steps that the lead scientist, acting as the teacher, had taken. Teachers shared what they wrote, and reflected together on what the lead scientist had purposefully done, why he had done it, and what they had been doing as learners. This was to highlight their awareness of the experiences, and to facilitate conceptual change learning about inquiry and to support teachers in the process of constructing meaning of their experiences in inquiry, both as a method for research and as a strategy for teaching science (Dutrow, 2005). Teachers then turned in their journals and received written feedback by a master teacher, modeling the hermeneutic dialectic process of Guba and Lincoln (1989). These "teacher hat" sessions continued on other days until all of the stages of inquiry had been described in terms of the learner and the lead teacher.

The stages of inquiry that were the focus of these reflective sessions originally were discerned by analyzing how the lead scientist naturally thought of ideas for marine ecology research and worked to develop experiments. The steps he tended to follow were delineated out into stages and named. Although these stages may seem arbitrary and unrealistic, it was done to help teachers better understand the process and assist teachers in understanding inquiry as a model. The stages of inquiry modeled in the MET program and discussed in the *inquiry on inquiry* sessions were

Stage 1: *orientation* (safety/comfort);
Stage 2: *fieldwork* (experience a provocative phenomenon that caused participants to ask questions);
Stage 3: *debriefing* (participants generate questions from observations);
Stage 4: *experimentation* (design/conduct experiment);
Stage 5: *data analysis* (analyze/display/write up results); and
Stage 6: *presentation* (participants present and discuss their findings with the whole class).

The intention of the program was for the teacher participants to experience inquiry and to understand the steps of one model of inquiry, as a way to see how they might adapt that model to their classroom teaching, rather than as preparation to conduct marine ecology inquiry per se with their students. The fact that several of the teacher participants taught marine biology was incidental to those teachers' participation in the program, and the program PIs asserted that no formal preparation in the sciences or background knowledge was required to conduct inquiry. As the lead scientist said, with "the audience of teachers taking the program, I make the assumption that they don't know anything about the subject" which would means that "the nature of the sophistication of the question that they posed, or hypothesis and the way they posed it" would not be at the level of complexity of that of a practicing scientist.

The MET program culminated in teachers adapting a lesson from their content areas using the model of inquiry they themselves experienced and reflected upon in the program. This transfer of the inquiry model was critical in helping teachers to see how the program's inquiry model could indeed be adapted to very different kinds of content areas, such as physical science. Program staff helped teachers to think through how their lesson needed modifications to employ all of the stages they had experienced in the MET program. All of the lessons teachers developed were found by program staff to be appropriate for inquiry, although during initial stages of development, most teachers in the program were unclear of how to take a lesson and adapt it to match the stages of the program model. For many of the teachers this was an intensive experience, because up until this point they had not yet applied their learning to a new situation. Many revisions were required of the lessons, and teachers "tried out" parts of their lessons (usually the provocative phenomenon) with program participants to see whether it would work to generate both interest and questions.

Once the teachers returned to their classrooms, they were asked to teach the inquiry-based lesson that they had developed in MET, videotape it, and answer a postprogram questionnaire about their conceptions based on their inquiry-based lesson. The expectation was that teachers would carry out one entire lesson in which students would generate their own questions, develop a way to investigate those questions, conduct data collection and analysis, and present findings and new questions. Again, the overall intention of the MET program was to give teachers experiences in scientific research in order for them to gain an understanding of scientific inquiry, and to help them to transfer this use of inquiry to the classroom (Granger & Herrnkind, 1999).

METHODS

This research is a mixed-methods, multicase study of four purposefully selected teachers who participated in a field-based RET experience in marine ecology. This study focuses on teachers' understandings and enactment of classroom inquiry before and after these experiences. Naturalistic evaluation (Erlandson, Harris, Skipper, & Allen, 1993; Guba, 1987) was selected, and member checking the researcher's understanding of teachers' actions *with* the teachers was a technique central to this research. Quantitative measures of the teachers' practice (via coding and tabulation of classroom questions and the STIR (Bodzin & Beerer, 2003)) also were employed.

Participants

The four teachers who were the focus of these case studies were Kaitlin, Michael, Renee, and Nate (all names are pseudonyms). Table 1 is a summary of the teachers' years of teaching experience and their school context. These practicing, secondary science teachers were selected purposefully from a larger group of secondary science teacher RET participants based upon a number of shared characteristics: strong science content knowledge, experienced teaching at the secondary level, deeply engaged in the MET program, and a stated interest in further developing their teaching.

It is possible that having such a willing group of teachers in the study provided us, a "best case scenario" for the results of this RET. What this scenario may have kept us from seeing

TABLE 1
Overview of Teacher Participants

Pseudonym, Ethnicity, Age, Degrees	Years of Teaching Experience	Course Pre/Post	Pre/Postlesson Topic and Length	School Context	Classroom/Resource Characteristics
Kaitlin, AA Female, 43, BS biology, MS in progress, science education	8	9th honors integrated science	Egg structure and function, 1 day Soil absorption, 4 days	1,322 students; Former Title 1 school, midsized urban setting; 75% AA, 3% A, 1% H, 20% W; F/R lunch 41%; school grade D (2005), C (2004); NW FL	Focus on standardized testing and reading, orderly arrangement, separate desk and lab area allowing for setup Notebooks emphasized, lab resources available
Michael, AA Male, 32, BS biochemistry, enrolled in science education graduate coursework	4	11th chemistry 9th physical science	P,V, and T relationships, 2 days Bottle rocket flight, 11 days	478 students; rural, grades 7–12; 65% AA, 22% H, 12% W; F/R lunch 75%; school grade D (2005); NW FL	Focus on attendance and participation, respect for others, sit at lab tables/stools for class Few lab resources, cluttered, equipment/electrical room in poor repair
Renee, EA Female, 34, BS secondary science education	11	7th physical science	Physical and chemical changes, 1 day Light and color wheels, 3 days	509 students; 90% W, middle class, rural-suburban, school grade B (2005), 30.3% F/R lunch; NW FL	Several subject classes, orderly arrangement, separate desks and lab table area Sufficient resources, beautiful room, prefers activity kits and preplanned laboratories
Nate, EA Male, 36, BS biology MS science education	4	10th biology 11th marine science	Exam review session, 1 day Wave action, 8 days	1,802 students; historically prominent public high school; midsized urban setting; 2% A, 3% H, 21% AA, 74% W; F/R lunch 11%; school grade B (2004 and 2005); NW FL	Focus on covering content, straight rows of desks, cramped lab area along walls, Gurgling fish tanks Note-taking emphasized, sufficient lab resources

were the pitfalls of the program, in that each of these individuals responded so favorably to the experiences of MET and was so eager to learn. But, in selecting individuals with many similarities, we sought to understand factors that influenced their differential responses and growth following the program.

Michael, who is African American, taught in a rural school with 87% minority population, 75% free-and-reduced lunch (F/RL), and a "D" school rating of student achievement by the state. His physics/physical science/chemistry classroom was poorly lit and had missing ceiling tiles, peeling paint, dysfunctional sinks and electrical outlets, and no access to gas. Kaitlin, also African American, taught in an older urban school with 79% minority population, 41% F/RL, and a "D" school rating. Her biology/integrated science classroom recently had been remodeled and was well lit, all was in good repair, and she had plenty of science equipment. A focus at both of these lower-rated schools was on reading and attendance.

Renee, who is European American, was in a rural-suburban school with 10% minority population, 30% of students on F/RL, and a "B" school rating. Her integrated science classroom was very large and bright, with a separate laboratory area, well equipped, all in full working order. Nate, also European American, taught in a historically prominent, midsized urban school with 11% minority population, 11% of students on F/RL, and a "B" school rating. His biology/marine science classroom had laboratory tables around the perimeter and gurgling fish tanks. The bright classroom with tall ceilings was crowded with desks, and had aging but sufficient equipment.

The first author spent 24 days with the teacher participants during the MET summer program, and another 34 days, total, observing teachers' postinquiry lessons and conducting interviews. There was additional teacher contact through e-mail and phone conversations, and sustained interactions over the next 2 years with three of the participants, who participated in a follow-up study on student learning with inquiry. In addition, two of the teachers were students in a course with the second author, who spent the semester in close contact with these participants and sustained contact for one of the participants as the student earned a master's degree. The third author was intimately involved in the MET program and familiar with the teachers in this study. The researchers knew these teachers well, both professionally and personally.

Data Sources and Analyses

One of the strengths of this study is the triangulation of data from multiple sources, shown in Table 2. There were six sources of data employed to describe teachers' pre- and postprogram understanding of and changes in conceptions and enactment of inquiry. Prolonged engagement with these teachers, and recursive loops of member checks with multiple data sources acted to confirm the trustworthiness of the analyses and reinforce the findings (Erlandson et al., 1993; Guba & Lincoln, 1989). Given the complexity of data collection and analyses each data source and its analysis will be discussed in tandem, linked to the research questions.

Inquiry Conceptions Data/Analyses. Participating teachers were required to complete a questionnaire used to describe their conceptions of inquiry, both pre- and postprogram. These questions addressed such aspects as describing key characteristics of inquiry, their primary learning goals for the lesson, how effective they thought the lesson was, and future intended use of the lesson and plans for using inquiry (see Appendix A for questionnaire).

TABLE 2
Overview of Data Sources and Analysis Techniques

Construct	Data Sources	Analysis Technique	Timing (Pre/ MET/Postprogram[a])
Inquiry conceptions	Questionnaires (Blanchard, 2006)	Teacher/learner inquiry continuum (TLIC) (Blanchard, 2006)	Pre- and postprogram
	Interviews/conversations	Member checking (Guba & Lincoln, 1989)	MET and postprogram
Inquiry enactment	Classroom recordings	Revised Bloom's taxonomy and other question coding (Huitt, 2004)	Pre- and postprogram
	STIR instrument (Bodzin & Beerer, 2003)	Coding and negotiation (Blanchard, 2006)	Postprogram
	Interviews/conversations	Member checking	Postprogram
Underlying goals, beliefs, and values	Classroom recordings	Analyze critical incidents (Crawford, 2000; Nott & Wellington, 1995)	Pre- and postprogram
	Interviews	Member checking	Postprogram
	Participant observations/conversations	Ask for explanations of what was observed	MET and postprogram

[a]Postprogram refers to data collected after the participants returned to their classrooms the year following the MET program.

Teachers completed the questionnaires after teaching their lessons. Likely as a result of this, teachers' descriptions of their classroom activities were very "practical" in nature. We coded these responses into the vertical categories of "content," "assessment," "teacher actions," and "student actions" using the Teacher/Learner Inquiry Continuum (TLIC) (Blanchard, 2006) (see Appendix B for TLIC). Pre- and postprogram questionnaire data for these teachers totaled 18 pages of single-spaced entries (all study data were single spaced and typed verbatim), and each sentence or phrase was coded into the TLIC. Teachers' responses in the categories ranged horizontally in the rubric from learner-centered (LC) conceptions of inquiry to teacher centered, a continuum based upon how teachers' worded their responses (e.g., "teachers will facilitate students' learning" coded into *somewhat teacher centered*). Teachers' pre- and postquestionnaires were coded independent from one another.

The first author spent every day of the program with the participants during the summer and observed all teachers as they taught their follow-up lessons. Conversations over the 2 years involved in this research allowed the first author valuable insight into how teachers were thinking about what they were doing. These conversations were documented in fieldnotes, and during the postprogram interview, a formal member check with participants was done using the first author's interpretations (Guba & Lincoln, 1989). Postprogram interview data (81 pp.) and typed fieldnotes (45 pp.) documented classroom observations and conversations with teachers.

Inquiry Enactment Data/Analyses. Preprogram lessons encompassed a broad range of classroom activities, not necessarily inquiry per se, but rather a snapshot of typical classroom practice by each teacher, or what they believed may be inquiry. Although these initial classroom recordings might be considered a limitation of this study, triangulation of multiple data sources and prolonged engagement with teachers suggest these data to be reliable indicators of teachers' practices prior to the program. Postprogram, the follow-up inquiry-based lessons, planned during the MET, were recorded via an audio recorder mounted on the teacher and a camcorder that captured the class as a whole.

The coding of all questions from transcripts of classroom recordings provided one way to document changes in lessons from pre- to postprogram. This focus emerged in tandem with the intense focus the MET program placed on the role of questions and questioning within the inquiry model it provided the teachers. We noted: who asked the question? (teacher or student); were the questions related to content?; what was the cognitive level of the question? (context and prior knowledge of students were key to coding); and at what stage of the inquiry lesson did they occur? The classroom recordings focused on the teachers' comments to students and interactions between the teacher and the students, and all were transcribed verbatim for analysis. All questions were analyzed, and content questions (both the teacher's and the students') were coded using a revised Bloom's taxonomy (Huitt, 2004). The following excerpt of Renee's Day #3 of her lesson on color wheels, below, illustrates an example of this coding. Renee's students have completed their color wheels and recorded their results from spinning them, so the interaction is in part a review of concepts the students already have learned. Out of context, these questions might be interpreted as higher level questions, but in this case they function primarily as a review.

T: What colors are in white light? **[Knowledge]**
S: Red, blue and green.
T: Ok. Red, blue and green are the primary colors of light, are they the only ones colored in? **[Comprehension]**
S: No.
T: What other colors are in it? **[Knowledge]**
S: Violet, blue, green, yellow, orange, and indigo.
T: Ok. Very good. All those other colors are absorbed and the red is what bounces back at you. How about the blue section. Can anyone explain that one? **[Prompt]**
S: Same thing.
T: Jason, why does this appear blue to me? What makes it look blue? **[Coded as one question–Comprehension]**
S: I don't know.
T: Amanda, why does this look blue? **[Repeat Question]** Make sure you pay attention Jason so maybe you can learn something.
S: It's colored blue.
T: Why do my eyes see blue? **[Comprehension]**
What is the reaction going on here? **[Comprehension]** Shanika? **[Orienting]**
S: (No response from student.)
T: What makes us able to see the desk? **[Comprehension]**
S: The light.
T: The light, but what is the light doing to the desk? **[Comprehension]**
S: Reflecting.
T: It's reflecting off, okay. So, what is the light doing to the color wheel? **[Comprehension]**

S: Reflecting.
T: Reflecting off of it. The difference is this looks red to us and this looks blue, right? So, I'm trying to see why that difference would happen because of the light to cause that to look different. Is the light coming in the same? Is every bit of light hitting everything the same? **[Comprehension]**
S: Yes, ma'am.
T: So, the light hasn't changed, so what must be changing? **[Analysis]**
S: What is reflected and absorbed.

We emphasize that this question analysis as but one indicator of changes in the classroom interactions that accompany inquiry enactment, which combined with the STIR (Bodzin & Beerer, 2003) and classroom observations of the teachers' teaching show patterns of change in lessons from pre- to postprogram. We do not argue that teachers' and students' use of questions themselves indicate inquiry. Rather, given the disparate nature of the lessons between participants and the emphasis placed on questions and questioning in the MET program, we find question analyses particularly valuable in characterizing differences in the nature of the teachers' instruction before and after the program (see Table 3 for a summary of Renee's questions on Day 3 of her inquiry lesson).

The STIR is an instrument that accounts for how student- or teacher-centered an entire investigation is, based upon who (1) generates the question; (2) plans the investigation; (3) collects and analyzes data; (4) formulates hypotheses; (5) connects findings to the literature; and (6) plans communication of results (Bodzin & Beerer, 2003). The five-row STIR rubric has four options along an inquiry continuum, with the left-hand column for "learner centered," and as you move across the table to the right, the columns are "somewhat learner centered," "teacher centered," "somewhat teacher centered," and "no evidence observed" categories. STIR also functioned as a reflective tool to increase a teacher's self-awareness of his or her enactment of inquiry, when the separate coding of the instrument by the teacher and the researcher was discussed (Blanchard, 2006). The STIR served as another vehicle to characterize the teachers' postprogram practice, and much of the insight gained from this analysis had to do with the teacher thinking required to apply the rubric.

The analysis of the STIR instrument involved the following steps: (1) both researcher and teacher recording what the teacher and student had done during the inquiry investigation, on separate instruments; (2) comparing results and noting discrepancies in coding; (3) using classroom transcription to review what had occurred; (4) renegotiating responses to the STIR based on realizations as to what had actually occurred/more complete understandings; (5) recoding one negotiated STIR instrument; and (6) the teacher further explaining their reasons/goals for what occurred in the classroom.

During the formal interview conducted after teachers taught their postprogram inquiry lesson, typed transcripts of the pre- and postprogram lessons provided a forum for the researcher to share initial interpretations with the teacher in an effort to confirm, disconfirm, or flesh out initial researcher interpretations. A second purpose of the interview was to review the separately coded STIR instruments and to negotiate a new, shared STIR instrument during the interview process.

Teacher Beliefs, Goals, and Values Data/Analyses. In our search to understand changes in teachers at the deeper levels described by Kegan (1994), we examined transcripts for evidence of teachers' goals and underlying beliefs and values. We found teachers' responses to students were far more informative in terms of teacher thinking when the student asked a question or made a comment that had not been anticipated by the teacher. Given that the

TABLE 3
Example of Categorizations of Teacher's Conceptual Questions Using Bloom's Taxonomy (Renee's Entire Day 3)

	Definition	Sample Verbs	Classroom Tallies
	Bloom's Level: Low[a]		
Knowledge	Student recalls or recognizes information, ideas, and principles in the approximate form in which they were learned.	Write, list, label, name, state, define	8
Comprehension	Student translates, comprehends, or interprets information based on prior learning.	Explain, summarize, paraphrase, describe, illustrate	67
	Bloom's Level: High[a]		
Application	Student selects, transfers, and uses data and principles to complete a problem or task with a minimum of direction.	Use, compute, solve, demonstrate, apply, construct	11
Analysis	Student distinguishes, classifies, and relates the assumptions, hypotheses, evidence, or structure of a statement of question.	Analyze, categorize, compare, contrast, separate	3
Synthesis[b]	Student originates, integrates, and combines ideas into a product, plan, or proposal that is new to him or her.	Create, design, hypothesize, invent, develop	0
Evaluation[b]	Student appraises, assesses, or critiques on a basis of specific standards and criteria.	Judge, recommend, critique, justify	0

Note: A separate table of student questions was also totaled.
[a]Low- and high-level questions categorized based on Hofstein, Navon, Kipnis, and Mamlok-Naaman (2005).
[b]Synthesis and evaluation are considered to be at the same level (Huitt, 2004).

teachers had not had the time to thoroughly consider these situations, we found teachers "thinking on their feet" in these situations, responding in ways they could not initially explain to us, ways that were perhaps closer to internally held values. We termed these points in the lesson as "critical incidents" (Crawford, 2000; Johnston & Southerland, 2001; Nott & Wellington, 1995). Transcripts from teachers' pre- and postprogram lessons were analyzed for critical incidents by (1) finding a section in which the teacher seemed surprised by a question, (2) determining the underlying reasons the teacher had responded in the way she/he did in terms of her/his teaching values/goals, and (3) conducting a member check with the teacher during the follow-up interview, then negotiating with the teacher an appropriate interpretation for what had happened (Guba & Lincoln, 1989). There were various numbers of critical incidents in the teachers' classrooms. The numbers were higher when teachers were trying something very different from their typical classroom practice. Examples of critical incidents are included in discussions of the teachers' practices.

FINDINGS

Although four purposefully selected teachers were the focus of this research, we represent only two of these teachers in detail (Renee and Kaitlin), comparing them to the remaining two (Nate and Michael) in the cross-case analysis. The following sections on Kaitlin and Renee include the teacher's background, individual data supporting the teacher's conceptions and enactment of inquiry, the teacher's goals, values and beliefs, and future plans for inquiry. The within case analysis is followed by a crosscase analysis of all four teachers, focusing on factors that influenced what each of the teachers learned from the MET experience.

Renee

> I want [my students] to talk. I want them to share their idea. . . . That's my whole goal, to get the students to think about what they know and connect it to what we are doing. . . . They're constructing this web that is their knowledge and I want them to make as many weaves or connection to everything else they can because the tighter the weave, the more [concepts] they catch. (Postprogram Interview, November 9, 2005)

Teacher Background. Renee was a European American, middle school science teacher in her 11th year of teaching. She had a BS in secondary science education and was certified in 6–12 biology, chemistry, and integrated science for the middle grades. She taught in a new school located in a rural county of northern Florida. During her first 2 years following graduation she taught students with varying exceptionalities, afterwards moving to a "regular" seventh-grade classroom. At one point, disappointed about the lack of support and feeling unenthusiastic about the materials in her classroom, Renee considered leaving teaching. Then she found a set of laboratory kits that energized her and enabled her to do more interesting things with her students. At the time of this study, she taught five periods each day: advanced and regular seventh-grade mathematics, reading, and two physical science classes. Renee described her "team" at school as having high expectations and strict discipline (including corporal punishment). She felt her students liked her and wanted to please her, a description which matched observations of the researcher (refer to Table 1 for a comparison of Renee's background to the others).

Renee's Predata. Renee entered the MET program in part "to move my classroom toward an inquiry-based curriculum" (although the preprogram data indicates she was unclear about the meaning of inquiry), and the monetary support provided by the program was helpful in allowing her to devote 6 weeks to this effort. Renee's preprogram lesson was conducted with a small group of students from her science class during her class period called "team time." In the lesson, Renee conducted a short review of physical properties of matter. Then, students followed a set of directions to work through a series of chemical or physical changes: breaking a pencil, passing a ball through rings, cutting clay and molding it, dissolving sugar cubes in water, mixing baking soda and vinegar, and lighting a candle. Next, the whole group discussed the changes, categorizing them as physical or chemical. The lesson lasted approximately 45 minutes. (See Table 4 for a comparison of Renee's pre- and postprogram lessons.)

Renee's preprogram questions dominated the lesson (97%), and the vast majority of questions were either recall or explanatory questions (90% lower level questions) (see Table 5). The focus of the lesson was on recall of previously learned facts about physical

TABLE 4
Description of Renee's Pre- and Postlessons

Lesson Period	Activity
Preprogram	Teacher review of content; students follow written directions to enact physical and chemical changes; group discussion to categorize events.
Postprogram	
Day 1	Students observe light through prisms; review previous knowledge of light; teacher demonstrates color wheels while students observe; students directed to make their own color wheels, choosing their own colors, and record observations.
Day 2	Students continue to construct and observe; teacher circulates, discussing progression and observations with various students.
Day 3	Students complete work, discuss findings, and post "favorite" color wheels; teacher and students discuss findings to connect color wheel and light behaviors; future experiments postulated.

TABLE 5
Renee Pre- and Postprogram Question Analysis by Day

		Preprogram	
Speaker		Teacher ($n = 90$)	Student ($n = 3$)
Questions asked	% of total (for teacher AND student)	97	3
Type of question			
Conceptual	% Total (for teacher OR student	70	14
	(% Lower)	90	100
	(% Higher)	10	0
Procedural	% of total	2	67
Other	% of total	28	19
		Postprogram (Day 1–3)	
Speaker		Teacher ($n = 199$)	Student ($n = 42$)
Questions asked	% of total (for teacher AND student)	83	17
Type of question			
Conceptual	% of total (for teacher OR student	57	43
	% Lower	84	61
	% Higher	16	39
Procedural	% of total	14	38
Other	% of total	29	19

Note: "Total" refers to specific column totals (referencing "*n*" for each column), *except* as indicated by teacher AND student data.
$n =$ Number of questions.

and chemical changes, and students' explanations of their understandings of these items. In addition, the students responded to preset questions as they worked through the directions. There was no presentation stage of findings, instead they were simply discussed by the teacher after each step was done.

Following the teaching of her preprogram lesson, Renee described herself as a "facilitator" who had students "perform a certain task" and "come up with a definition" for and "understand the properties of different substances." Her primary focus was expressed in terms of what students were doing, and her impression from the students' actions was that students were internalizing the content. Renee's writing portrayed her at the center of the inquiry experience, orchestrating students' completion of tasks to understand "patterns and generalize" about scientific knowledge.

Renee was very interested in helping her students to learn science content. Even though her preprogram activity was a lesson that has many of the "essential features" of inquiry (Olson & Louckes-Horsley, 2004), we would classify it into what Schwab (1960) calls "Level 1" and Colburn's (2000) "guided inquiry," in which

> the teacher provides the students with the question to be investigated and the methods of gathering data. What they will find during the activity is not immediately obvious to the students, but the teacher is there to guide them toward an expected conclusion. (Settlage & Southerland, 2007, p. 9)

Renee believed her role was to guide the students to preset findings. When examining her coded questions, she commented, "[My teaching is] kind of heavier on the teacher side. . . With the population I am dealing with, that's kind of par for the course." "Doing inquiry" for Renee at this point was a very traditional, teacher-directed laboratory experience, in which students "discovered" known concepts through interaction with materials.

Renee's Postdata. As shown in Table 4, Renee's 3-day postprogram inquiry lesson focused on light and light absorption by various colors. A substantial portion of the lesson focused on students' observations about light as it passed through a prism and the interaction of their questions and the teachers' questions. Renee shined a light through a prism and part of it passed outside of the prism. So there was light that was bent and light that was not, and what began as "tell me everything you know about light" became "what determines what it looks like as far as its color" as well as issues of brightness (the prism light was dimmer) and whether the light bent and why ("compare the path it travels without the prism"). Students discussed how light "scatters" and "reflects" and asked such questions as "how does a prism turn from clear to white and then to a color?" In response to these questions, Renee asked more questions, such as "Does it turn a color?" and "Describe intense to me. How would you measure it?"

The analyses of the critical incidents suggest that postprogram, Renee consistently turned student questions, comments, and explanations back to her students to consider:

> S: If you change the light bulb, can you change the amount of light it gives off?
> T: What do you guys think?
> S: No.
> S: It is the size of the filament inside of the light bulb.
> T: Oh. You think it is the filament inside of the light bulb.
> S: It's the watts.
> T: How many watts it has. How could you find something like that out?
> S: On the label.
> S: On the computer.
> T: What does it say on the label?
> S: The amount of watts.

T: But how could you tell what is really making it brighter?
S: An experiment.
T: An experiment. How would you set it up?
S: Use like a camera on the light and find out what the wattage is for different lights and turn the dial up.
T: Ok. That would be a good one. Can anyone think of another way of testing it?
S: Get a huge light bulb and a little light bulb and increase the same amount and see whichever one blew first.
T: See whichever one blew first? Yeah?

Even when a student's response did not appear to make sense (such as "adjusting the wattage on a camera"), Renee struggled to accept the response on some level to build the student's confidence, demonstrating that she "believes in them" and "wouldn't give up" on trying to help them to understand. Although Renee accepted student responses, she also led them to consider using investigations to try to answer their questions.

About 30 minutes into the class period, Renee introduced a color wheel. She asked such questions as "Now what makes things look red?" and then eventually said, "The light produces white light which has, as we just saw, split apart and it made all these colors. Right?" Then Renee asked students to make observations about what happened when she spun a color wheel she had made, a white circle subdivided into equal, pie-type sections, each section colored one of the colors of the light spectrum (red, orange, yellow, green, blue, indigo, and violet, with one section left neutral—eight sections instead of seven for teacher ease of marking the circles). Students watched while she spun the wheel on the point of a pencil and saw all the original colors blend into what looked like the color white. Students then created color wheels, following Renee's direction to "Do different patterns. . . so we can experiment and see what you guys observe." Students collected data on what they observed while they were spinning their wheel (refer to Table 4 for a comparison of pre- and postprogram lessons).

The question interaction for this lesson was again teacher dominated (see Table 5). However, there was a shift in the nature of Renee's questions to 12% more procedural questions, and 13% less conceptual questions. This indicated a role shift of Renee's from the dispenser of information to more of a laboratory support role, helping students with finding or manipulating materials. Renee's questions also showed increases in the percentage of high-level questions (with a 6% increase).

The most dramatic change pre- to postprogram lay in the nature of students' questions, which went from having asked no higher level questions preprogram to asking 39% high-order questions, with an overall increase of total questions asked by 29%. Postprogram, students were asking 15% more of the questions than they had preprogram, and more of these (29%) were of a conceptual nature.

The TLIC coding of the postprogram questionnaire indicates Renee's focus had visibly shifted to what the students were doing, with a full 90% of her statements coded on the student centered half of the rubric. The following sample of her writing demonstrates this shift in her focus of inquiry:

> By determining the colors they will use on the color wheel, the students are empowered to seek their own answers and are more interested in the outcomes. When they observe the outcomes and participate in the discussion about them they are more likely to remember the concept. By creating experiences using touch, kinesthetic, visual and auditory senses, the students have a greater opportunity to integrate this new information into their existing scheme.

Renee's postprogram writing focused on what the students were doing, and teachers' actions were framed in supportive terminology. Renee used language adopted from the MET program: the class observed a "provocative event," students were "empowered" and doing "fieldwork." She wrote about students "internalizing this concept" and her goal was "to help insure that the students' understanding of light is not merely a surface one." The focus was on students' reasoning during their small group discussions. She described her role as guiding and supporting students' meaning making.

The STIR analysis indicates that Renee's students were working quite independently in terms of collecting data and trying to determine the meaning of their results (see Table 6 for summary data). Students generated questions from prism observations, they investigated the teacher's preset question, "What happens to light if you combine different colors on the color wheel?" and were given fairly explicit instructions on how to create the color wheels. The students selected which colors and in what order, etc., but each group employed the same basic design, Schwab's Level 1 inquiry (Settlage & Southerland, 2007). Renee acknowledged her students had not tested the questions they generated on Day #1, but rather the question she had assigned.

The last question to the postprogram questionnaire asked teachers what they would do differently with the questionnaire in the future. Renee wrote,

> In the future I will make the initial fieldwork portion of the lesson shorter by requiring each student to do only one color wheel before we start generating questions. This will leave more time for individual experimentation and presentation, which had to be cut short because of lack of time.

In the year after the program, Renee still seemed ambivalent about the "fit" between inquiry and *her* classroom ("time is the issue"). Renee could think through how to make a lesson more inquiry based when prompted by a conversation with a researcher, but she stopped short in considering or planning for its incorporation throughout her curriculum. In our interviews, she explained her need to have all of the materials at hand well in advance of any lesson to consider doing anything new with existing science topics, a need that overwhelmed any further movement toward inquiry. After talking about how to make the inquiry lesson more student centered, Renee decided that having a set of 30 flashlights and individual acrylic color circles would allow the students to do their own experimentation, and would remove her from the center of the lesson.

Postprogram Renee struggled with the contradictions of wanting students to have more "hands-on" experiences and her desire for those experiences to be instructionally useful for teaching specific content. In light of the RET experience, in which the second laboratory investigation promoted more of a Level 3, open-inquiry approach, Renee's approach was still very teacher centered. When asked whether ideally she would like to get more student centered she said, "Yeah. I want that. I've not been able to figure out how to do it and maybe it's not the curriculum, maybe it's just me." At the end of her first year postprogram, Renee's use of inquiry was relegated to the lesson designed for the MET program.

Summary of Changes in Renee's Conceptions and Enactment. As shown in Table 6, in postprogram conceptions of inquiry data, Renee's writing framed students at the forefront with the teacher receding into more of a guiding role. Renee also adopted some of the terminology from the program, which focused on student empowerment and the generation of questions from "provocative events." There is a visible shift in the evidence of Renee's conceptions of inquiry toward more student-centered teaching, with matching

TABLE 6
Comprehensive Table of Participant Data Analysis

Analytical Dimension	Subcategory	Kaitlin Pre	Kaitlin Post	Michael Pre	Michael Post	Renee Pre	Renee Post	Nate Pre	Nate Post
TLIC (conceptions of inquiry)	LC	23	63	9	23	10	57	0	38
	Somewhat LC	23	19	43	47	52	33	8	23
	Somewhat TC	47	25	35	30	38	10	8	31
	TC	15	0	13	0	0	0	85	8
Question analysis	*Speaker*								
	Teacher	82	76	93	67	97	83	75	72
	Student	18	23	7	33	3	17	25	28
	Type								
	TContent	61	63	100	66	70	57	95	74
	TNonContent	39	37	10	34	30	43	5	26
	SContent	79	45	50	30	14	43	69	71
	SNonContent	21	55	50	70	86	57	31	29
STIR analysis (inquiry enactment)	#1 Question		LC		SLC		SLC		SLC
	#2 Design		SLC		SLC		SLC		SLC
	#3 Analyze		SLC		LC		LC		SLC
	#4 Explain		LC		LC		LC		LC
	#5 Literature		NE		NE		NE		NE
	#6 Present		SLC		STC		STC		STC
Future orientation to inquiry		Integrate NOS into many topics throughout the year; adapt “boring” lessons into inquiry-based lessons, add GEMS lessons.		Expand more topics into inquiry-based lessons, rethink all lessons in terms of conceptual learning and making them more hands-on.		Acquire materials for more contained, hands-on labs and reteach what she has supplies to teach.		Reteach the waves lesson, make more efficient; possibly add one inquiry-based unit to biology course.	

All values are in percent.
TLIC = Teacher/Learner Inquiry Continuum; LC = Learner Centered; SLC = Somewhat Learner Centered; STC = Somewhat Teacher Centered; TC = Teacher Centered; NE = Not Evidenced; TContent = Teacher Content Questions; TNonContent = Teacher Noncontent Questions; SContent = Student Content Questions; SNonContent = Student Noncontent Questions; NOS = Nature of Science.

language that describes concern for students' learning and sense making. Through her use of the program language, it is clear that the changes in Rouge's descriptions were linked to her experiences with the MET program.

In analyzing these data and in the follow-up interview and continued conversations with Renee, it is clear that she was thinking about this issue of student centeredness and mulling over the changes that would be required to act in ways to shift her classroom further along the continuum toward the more open-ended instruction of inquiry-based science. Question data strongly support shifts in teacher and student roles during the color wheel lesson, and an increased use of higher level application questions by students. Renee readily recognized many contextual barriers to a more consistent use of classroom inquiries: having appropriate materials, time to plan ahead, and the level of her students both cognitively and in terms of classroom management. On the other hand, it is uncertain whether Renee detected clear distinctions between her preprogram and the postprogram lessons, beyond the role shifts and her use of a science kit versus something she had devised. There is no evidence to suggest that Renee intended to apply her new inquiry practices throughout her curriculum. Instead, the impact of the MET program was limited to the lesson she designed for the MET program.

Kaitlin

> When I first heard about [inquiry] it was years ago and it was the new thing and people around me were doing it. . . . I remember thinking that it was a ridiculous notion for me, because. . . It was basically about tossing the book out the door and you let the kids go for it.. . . . It wasn't until [Science Teaching and Learning] class where I saw the continuum [of inquiry] and got a better idea of it, that there is a continuum in there where you can work based on how you feel your students can handle, and progress. . . . It then made more sense to me. (Post Program Interview, September 5, 2005)

Teacher Background. At the time of this study, Kaitlin was in her 10th year of teaching. Kaitlin held a BS in biology. Her teaching certifications were in 6–12 biology and integrated middle grades science, and she was a 2004 Teacher of the Year awardee at a previous middle school assignment. At the time of this study, Kaitlin taught ninth-grade honors integrated science and tenth-grade biology, and in the year of this research she was involved in a MS program in science education. Kaitlin's quiet manner had a reserve and formality that one might briefly mistake as stern, an impression that was quickly dispelled by talking with her and watching her interact with her students. Kaitlin took great pleasure in her interactions with students, and they clearly respected her. A typical class began with students seating themselves and looking to an overhead projection of the day's journal questions. Kaitlin honored students' comments and required students to listen as other students spoke. She expected their participation, but rarely used praise to support it. Instead, Kaitlin reserved praise for unusual or particularly insightful contributions (for a comparison of Kaitlin's background to the other teachers, see Table 1).

Kaitlin's Predata. Kaitlin's primary motivation to participate in the MET program was to earn credit hours toward her master's degree in science education. She also wanted to refresh her "knowledge of research techniques as they relate to the nature of science and to learn about marine ecology." Kaitlin's preprogram lesson required students to examine a cracked egg's structure with a partner, predict the functions of the egg structures, and then share their ideas with the class. One of Kaitlin's goals was to "debunk the belief that

TABLE 7
Kaitlin's Pre- and Postlessons

Period	Activity
Preprogram	Students examine and predict function of egg structures, sharing with class; teacher attempts to detect misconceptions and misinformation.
Postprogram	
Day 1	Students study soils, recording observations; class shares observations; teacher assists in reshaping observations into questions; students directed to consider how soils behave in water.
Day 2	Students discuss previous experiences with soils and water; students generate testable questions; students create experimental methods for testing of questions.
Day 3	Students test nature of soils using designed methodologies.
Day 4	Students finish data collection; students prepare posters of findings and the present them to the class.

students have about fertilized eggs versus unfertilized eggs in the supermarket." She thought the class discussion would allow "the teacher to detect misconceptions or misinformation." She also wanted the students to "dialogue among lab group members and to listen and share ideas" with the dual hope that it would "allow the students to take more responsibility for their learning" and enable her, the teacher, to know what ideas needed to be addressed in the class discussion with regard to "[im]plausible" beliefs (see Table 7 for a comparison of Kaitlin's pre- and postprogram lesson).

Kaitlin's questions dominated the lesson in the preprogram lesson, and students asked about one fifth (18%) of the questions (see Table 8). The focus of the lesson was the teacher asking for explanations and the students providing their reasoning. Thus, nearly all of the questions code as low-level recall (knowledge) and description (comprehension) questions. The selection of Kaitlin's lesson was based on discussions of using inquiry-based methods in her graduate coursework. She described her lesson as "beginning to try [new] things out. [The students] weren't really used to me asking them so many questions. So, this was new to them as well."

When Kaitlin's preprogram questionnaire responses were coded on the TLIC, over half of them were framed in terms of her actions, a diagnostician trying to determine whether the students were thinking in plausible ways about the eggs (see Table 6). Her focus was on a mixture of what the teacher and the student were doing, and she used terminology from her recent graduate course referring to conceptual change models and the nature of science. Kaitlin comments did not mention assessment, which seemed unusual given her school's focus on raising low test scores.

Kaitlin's preprogram lesson modeled some of the observational aspects of an inquiry-based lesson. It was a very different type of lesson from what had been typical of Kaitlin's lessons in the past in that it was exploratory. She struggled to not answer students' questions, but rather have students work through questions with students in their groups. This introductory inquiry lesson lacked an experimental design, data collection, or a presentation of research findings. The focus was on students' explaining their thinking about eggs to the teacher.

Kaitlin's Postdata. Kaitlin's postprogram lesson was on soils, as detailed in Table 7. Students began by looking at the different soil types in their groups. In her instructions,

TABLE 8
Kaitlin's Pre- and Postprogram Question Analysis by Day

	Preprogram		
Speaker		Teacher ($n = 89$)	Student ($n = 22$)
Questions asked	% of total (for teacher AND student)	82	18
Type of question			
Conceptual	% of total (for teacher OR students)	61	79
	(% Lower)	98	87
	(% Higher)	2	13
Procedural	% of total	<1	16
Other	% of total	39	5
	Postprogram (Day 1–4)		
Speaker		Teacher ($n = 228$)	Student ($n = 71$)
Questions asked	% of total (for teacher AND student)	76	23
Type of question			
Conceptual	% of total (for teacher OR students)	63	45
	(% Lower)	65	71
	(% Higher)	35	30
Procedural	% of total	10	34
Other	% of total	27	200

Note: "total" refers to specific column totals (referencing "*n*" for each column), *except* as indicated by teacher AND student data.
n = Number of questions.

Kaitlin explained, "We are using our senses to gather information. Today I want you to do exactly that... We are going to go back and look at some nature of science things we've been doing and some set-ups... " The intention of Kaitlin's lesson was for students to determine how different soils absorbed water. Students made a variety of observations about soils. One student offered that her soil was "flaky" to which Kaitlin replied, "What do you mean by that? 'Flaky' means a lot of things to a lot of people." Later, a student suggested that placing water on soil was a chemical reaction. Kaitlin's response sounded a bit like an annoyed mother:

> When you were little and you played with mud pies and things... do you really expect something to be different about mixing soil and water? I mean, otherwise when it rains there we'd be having chemical reactions everywhere.

Kaitlin was not willing to let students make contributions that she knew were at odds with their life experiences. Later, during the discussion of the activity, students were asked to generate possible questions about soils as a class and were told to "think about how the soils behaved in the presence of water" as homework. The next day, students ultimately were lead to Kaitlin's general question, "How do different soils absorb water differently?" This was similar to how the MET program scientist led the teachers to the general question "why do periwinkle snails climb the marsh grass?"

On Day 2 of Kaitlin's postprogram inquiry lesson, students were in laboratory groups, trying to decide how to set up an experiment that would discern differences in three soil types based upon water absorption. Here is a critical incident excerpted from Kaitlin's interaction with one group:

> T: If you're going to take an eyedropper and just drop water on the soil, how are you going to determine how much absorbs the most water?
> S: 'Cause um, put a certain amount of soil in, and you can feel it and then. . .
> T: How does that tell me how much, just by your feeling it? Is that objective?
> S: Like which one is more. . . moist. . .
> T: How can you feel that?
> S: One's thicker than the other.
> T: That's not going to give you any quantitative data on how much. The question is "how much water will be absorbed?." That's your question, right? So how are you going to determine how much? By feeling it can you give me some quantitative data (. . .) just by doing that?
> S: Give each soil a certain amount of water and keep pouring it in until it absorbs. . .
> T: But how are you going to tell me how much? How are you going to tell me that this one absorbs this amount, this one absorbs this amount and this one absorbs this amount? How are you going to do that?
> S: We could measure how many drops of water we're putting in there.

In this critical incident, Kaitlin was surprised by the student's suggestion to measure the moisture content of the soils by feel, and she responded by going back to issues that she understood to be important in science, such as validity, objectivity, rigor, and precision in their language. The next 2 days involved students' designing experiments, collecting data, and presenting findings to the class using a poster (see Table 8 for comparison of Kaitlin's pre- and postprogram lesson).

Transcript data show that Kaitlin's students were somewhat self-sufficient in their investigation of soils. Teacher control was least evident on the day that the students were making observations. In contrast, when the students began to work on designing the experiment, they asked many more questions of Kaitlin, seeking support for their designs. In response, Kaitlin asked students questions to try to guide them to making what she felt were appropriate choices, ultimately designing investigations that would produce useful data.

There were substantive differences in the percentage of high-level questions asked both by Kaitlin and the students in the postprogram lesson (see Table 8). A full 35% of Kaitlin's questions were coded at or above the application level, as were 30% of her students' questions. This represented an enormous shift on Kaitlin's part (2% high-level questions preprogram) and more than a 40% increase of her students' (13% high-level questions preprogram). The other notable shift was the increase of procedural questions asked by all. Kaitlin's procedural questions increased from nearly zero, preprogram, to about 10% of her questions. In contrast, students' procedural questions doubled postprogram. During the postprogram experimental phase of the inquiry lesson, Kaitlin and the students were interacting over equipment use and supplies, and these needs nudged Kaitlin into a greater support role versus a greater focus on conceptual questions. More detailed data coding revealed that the highest level questions were asked by the teacher on the day students presented their findings. Kaitlin asked "What else would make the results more valid?", engaging her students in higher order questions as a way for them to make further sense of experimental design issues, in addition to trying to help them make sense of the relation of their work to the work of others.

In the postprogram questionnaire, Kaitlin's entries are coded more toward the LC half of the TLIC rubric (63% LC and 19% somewhat LC, totaling 82%) (see Table 6 for these data). There is a noteworthy focus on students' actions, coded from statements such as "The experimental design and data analysis are constructed by the student" and "The students are actively participating in their learning, they must think or ponder their observations, and they use the skills of science i.e. observations, inferences, etc." In the interview, Kaitlin explained, "inquiry... is really about the power shift" echoing some of the discussion in the MET program. Kaitlin conceptualized inquiry as a process of thoughtfully devised investigations carried out using appropriate science process skills. This was in conjunction with students using background knowledge to craft a "sensible" investigation.

The STIR analysis shows that students were engaged in a fairly student-centered version of inquiry that Kaitlin saw modeled in the program, Schwab's Level 2 inquiry (Settlage & Southerland, 2007). Kaitlin's students came up with questions from their observations, which were crafted into testable questions. When Kaitlin's students did not gravitate toward a specific question, Kaitlin nudged them toward one (i.e., "How much water do the soils absorb?"), which she pointed out to the researcher was "what they did in the summer program" (see Table 8 for categorical tallies for this lesson).

Insight into Kaitlin's underlying goals, values, and beliefs was derived from her responses during the critical incidents in her classroom and her later interview reflections upon those incidents. Here are some of Kaitlin's musings,

> I think I still struggle with that whole idea of letting [students] do something... if it is wrong... it makes more sense to try to help move them or direct them to the way it should be done and help them think about the process of getting there... I think it is probably more about me and because of that that I see it as unproductive. I also see [completely student designed explorations] as wasting their time.

> I do kind of treat them like I treat my own children... [M]y whole relationship... with my students is a very complicated mesh of things... this authoritarian, "I said do it", but at the same time, I really try to show them respect in the way that I deal with them.

When we discussed Kaitlin's plans for the future, she explained that she had already altered many of lessons that she commonly employed to incorporate more inquiry, for instance she now employed a paper towel lab to address the basics of experimental design. She also went into great detail in describing an activity for testing pH on unknown materials as a way for students to learn about pH in common substances and extrapolate its relevance to pH in human blood. She had created this latter lesson by revising a traditional minilaboratory from the textbook to increase the level of inquiry employed. In the year following this research, Kaitlin used an online-nature of science curriculum in her classes, a curriculum that employed guided inquiry to teach both nature of science and ideas around molecular biology.

Summary of Changes in Kaitlin's Conceptions and Enactment. Between the pre- and postprogram periods, there were substantial shifts in Kaitlin's conceptions of inquiry and her classroom practice. Prior to submitting her preprogram lesson, Kaitlin had never taught using inquiry-based methods, due to her negative impressions of inquiry that she had seen modeled in teacher in-service programs. However, the MET program's emphasis on questioning and the use of questions was a good fit for Kaitlin's natural style of instruction, which privileged students' current knowledge. Her use of student questions to generate research questions for classroom investigations was completely new, and although she was able to carry out the lesson with her students in a manner that closely matched the program model, Kaitlin continued to struggle to allow students to make mistakes.

Kaitlin described the MET program as giving her a concrete example upon which to "hang" her theoretical knowledge of learning, inquiry, and conceptual change. The sense making that had begun in her master's level learning theory class was applied as she participated in the MET program and then returned to her classroom. Postprogram, Kaitlin conceived of inquiry as a flexible, changeable teaching approach, one that was a part of her repertoire to build on students' prior knowledge and skills. Postprogram, her understanding of inquiry was intimately linked to her knowledge of learning theories, allowing her to understand it as a teaching approach closely connected to students' knowledge and actions.

DISCUSSION

Crosscase Analysis Findings

In the following section, we looked across the four cases to determine what commonalities existed for these practicing teachers; what were the shared patterns in their changes in conceptions of inquiry, in their enactment of inquiry, in their use of questions, and in how were these changes were linked to the RET experience?

Teachers' Changes in Conceptions of Inquiry

Preprogram. When queried in the preprogram questionnaire, Kaitlin referred to inquiry as "a method of teaching science." Michael described it as "what science is and how it is practiced." Both went on to provide descriptions of the teachers facilitating learning through inquiry, with Kaitlin focusing on learner responsibility and Michael focusing on the use of inquiry to foster student learning of concepts needed for scientific literacy, in the context of a conceptual change model. Renee wrote that "an inquiry investigation is one in which the students are asked to perform a certain task and observe the outcomes." All three of these teachers described the preprogram lesson they carried out with the students as matching what they thought of as inquiry at that time.

Nate responded that "inquiry teaching is a paradigm which allows the teacher to become less the imparter of knowledge, and more of a guide," but he noted that his preprogram lesson (which he was free to select) did not employ inquiry. Nate also wrote, "inquiry teaching builds on the prior knowledge of the student, providing a way for the teacher to use curiosity as motivation for learning." Through his past experiences working at a marine laboratory, he had more inquiry-based science experiences preprogram than any of the teachers in the program, and Nate also had earned the only master's degree in science education. Although on the questionnaire Nate used some terminology he had learned from his graduate studies some years earlier, he openly talked in negative terms of the educational focus of the master's program, clearly highlighting his science experiences as the ones that had been more valuable. Thus, he called up this educational knowledge to get into the MET program, but seldom accessed this knowledge throughout the remainder of the program or thereafter.

A common thread to all of these teachers' responses was that they situated the teacher as the one who was causing the inquiry to take place, by "facilitating" or "harnessing" or "asking" students to do something. Prior to coding the questionnaire entries on preprogram conceptions of inquiry, our general impression was that these teachers, given limited experiences with inquiry, were "guessing" at what it entailed and trying to "do well" on the assignment as entry into the MET program. Their inquiry conceptions were vague and broad and contained portions of "the scientific method." Of the four teachers, portions of Nate's responses were the most closely matched to the MET program description of inquiry, with Kaitlin and Michael's responses perhaps in the middle, and Renee's the least descriptive. Although, as we explained in the selection of these teachers, these teachers' initial notions of inquiry were among the most sophisticated of any of the program participants studied (Blanchard, 2006).

Postprogram. In reflecting on their teaching of the postprogram inquiry-based lessons, all of these teachers described their conceptions of inquiry-based science teaching in ways that were more LC following the MET program (see Table 6 for summary data of all teachers). That is, these four teachers were thinking much less about what they were doing and much more about what the students were doing. Their references to their actions in the classroom postprogram primarily described their roles in support of the students' investigations. The shift in Nate's data was the most remarkable, in part due to the nature of his preprogram lesson (an exam review), although additional data collected suggest the coding of Nate's lesson as characteristic of his typical teaching approach.

Changes Linked to the Research Experience for Teachers Experience. In analyzing teachers' postprogram conceptions of inquiry, it was evident that teachers were reflecting on the roles played during the MET program to think about their own classrooms. In their classrooms, they now were acting as the lead teacher instead of the student, and regular comments by the teachers gave evidence that the reflective process of looking at the stages of inquiry was useful in helping them plan for their classroom practice. For example, both Renee and Kaitlin discussed how they "led" students to the inquiry question, but then pointed out that they had also been led to the "why did the snails climb the marsh grass" question during the MET program. The teachers were thinking very much in terms of the program model sequence and vocabulary as a way to organize the inquiry-based investigation of the students.

Teachers' Changes in Enactment of Inquiry

Preprogram. Three of the teachers carried out their preprogram lessons during one class period. Michael used two class periods, and his lesson involved students first doing a short laboratory related to the relationship between temperature, pressure, and volume, and then debriefing on it. Teachers had a vague sense that there should be a focus on the students and some sort of investigation, but were unclear how to achieve "inquiry." In Nate's case, he had the most laboratory experience, yet observations in a different laboratory indicated a "watch what I do to the shark and then you do it too" method, in which he asked only procedural or low-level questions. Michael and Kaitlin seemed to have the greatest interest in probing for student understanding, yet most of their questions remained at the descriptive level. None of the teachers seemed to have a sense of how to set up an investigation with their students, and their activities would have coded for a scant number of the categories of the STIR instrument.

Postprogram. Postprogram STIR data corroborate that three of the four teachers' postprogram enactment was solidly focused on students actively designing and conducting the investigations, as modeled by the MET program and mirroring Schwab's Level 2 inquiry and Colburn's guided inquiry (Colburn, 2000; Schwab, 1960). Renee's classes engaged in the same set of steps, but her the fact that her color wheels were largely prescribed persuaded us to describe her postprogram inquiry as closer to Level 1 inquiry, despite the more LC feel to the class. In the postprogram lesson for each of the four teachers, the majority of the postprogram enactment data were coded at either LC, or somewhat LC for all of these teachers on the STIR instrument (Bodzin & Beerer, 2003). The only component of the STIR instrument that was not done (and therefore not coded) by any of the teachers was students connecting what they did to the literature.

Changes Linked to the Research Experience for Teachers Experience. All of the teachers employed the stages modeled in the MET program. Indeed, the MET program had not explicitly modeled looking to the literature to see what else was known about the topic, and therefore was excluded from the inquiry modeled by these teachers. Although the teachers varied in their abilities to achieve the goals of each of the inquiry stages of the MET model (Renee gave students her question despite questions they generated), there was a clear link from the teachers' postprogram lesson plan and that of the MET program, in stark contrast to the preprogram lessons.

Changes in the Use of Questions During Inquiry Enactment

Preprogram. During the preprogram lesson, Michael asked 93% of the questions, all of which were conceptual in nature (see Table 6). More detailed data indicate that 96% of Michael's questions were at the comprehension level or below, as were those of the students. This pattern was similar across all of the teachers, and preprogram these teachers were asking the majority of the questions, ranging from 75% (Nate) to 97% (Renee). At most, teachers' questions asked students to describe either what they had already learned or what they were observing. Nate asked no higher level questions, Michael and Kaitlin each asked one, and Renee asked the high of eight, which was 10% of the questions she asked her students.

Student questions were few in the preprogram lesson, and the highest number of student questions asked in these teachers' preprogram lessons were four questions asked during Nate's preprogram lesson. Procedural questions were especially low in number, with most being asked by the student (two in Renee's classroom and six in Nate's classroom) and virtually none by the teacher (detailed data for these teachers are reported in Blanchard, 2006).

Postprogram. Postprogram data (see Table 6) reveal that all four of the teachers were asking fewer of the questions in the classroom and that the students were asking more questions. In addition, there was a dramatic increase in the percentage of higher level questions (Anderson & Krathwohl, 2001; Hofstein, Navon, Kipnis, & Mamlok-Naaman, 2005) that were asked, both by the teachers and by the students, compared with preprogram data. Renee's classroom data were the most startling, with a change from 0% higher order questions on the part of the students, preprogram, to 39% of the students' questions being at the level of application or above, postprogram.

Another shift for all four teachers was the enormous increase in the number of procedural questions they asked; virtually none preprogram, and to up to a third of the total questions postprogram (see Table 6). Teachers asked many of the procedural questions on the investigation days, when they acted primarily as laboratory assistants and materials helpers as the students worked setting up labs and collecting data. This corresponds to some of the roles Lappert (1996) discussed in his earlier study of Cap, the lead scientist who modeled his inquiry for these teachers. Inquiry in these teachers' classrooms was indeed different postprogram.

It is important to recognize that question analysis has the strength of providing quantitative support for the observational data of classroom as well as the limitation of not "telling" the whole story of enactment. In the case of Renee, her students' procedural questions were high preprogram, because they asked for copious instructions in a step-by-step lab on physical and chemical changes. In the postprogram lesson, Renee's students took ownership of the investigation with the color wheels, and team members asked questions of each other rather than Renee, evidencing less dependence on the teacher (although student-to-student interactions were not recorded for this study). Alternately, the increased percentage of procedural questions in Michael's classroom (0% preprogram for both teacher and student, postprogram 15% teacher and 34% student) accounted for the students trying to find materials to assemble their bottle rockets and Michael asking for clarification as to how to help them do so.

Changes Linked to the Research Experience for Teachers Experience. Teachers were modeling the stages of inquiry from the MET program when they carried out their lessons, attempting to ask the sorts of questions they had analyzed and experienced during the program. Students' questions resulted from the teachers' questions, and in all of the classrooms the patterns were very similar: the stages of inquiry very much were associated with types of questions (e.g., procedural and higher order) that had been nearly absent preprogram (Blanchard & Davis, 2006).

Teachers' Underlying Thinking and Long-Term Goals

In postprogram interviews, teachers debriefed very differently from one another and it was clear that their thinking about these lessons was very different. For instance, Kaitlin discussed in detail her concerns about how to support students' learning during the soil investigation, wondering whether she may be holding the students back from becoming more independent with their investigative designs, while simultaneously wrestling with how to keep students' frustration level at productive levels. There seemed to be more focus, postprogram, on Kaitlin's attention to students' sense making, perhaps as a result of Kaitlin now gaining more experience with using inquiry-based methods.

Nate discussed the postprogram lesson primarily in terms of students' conceptual learning. Nate said,

> My goals were very much to try and get the concepts by them of why waves behave the way that waves behave and how they were formed, what made them break, you know, what. . . you would expect them to learn when they did [a] kind of a unit. 'Course they all did their own Power Point and they did a pretty good job on them. So I was pleased that [they had] a pretty good understanding of what they looked at.

This was a noteworthy shift from Nate's preprogram lesson, in which students were simply checking correct answers to test questions with Nate doing little to explain the material. Postprogram, Nate is much more focused on students' rational processes, shifting away from finding the right answer to test questions toward students independently determining investigative designs.

Michael was focused, both pre- and postprogram, on students' conceptual understanding, interspersing his comments with encouragement and humor. Preprogram, students in Michael's class constructed air thermometers as directed and made predictions about what would happen when they added ice to the funnel. At this time, Michael was intensely focused on the conceptual changes of his students and tried to scaffold them to the concepts he hoped they would learn. Postprogram, Michael still was focused on students' understanding (in this case, bottle rocket designs) but he was less the center of the action, not guiding the students' "best" designs. In the following data clip of the initial brainstorming session on Day 1 of the postprogram lesson, Michael encouraged a student to share ideas of what factors might influence how rockets fly.

> Michael: Go on, Ms. Franklin. Let her speak, let her speak.[Quieting the rest of the class.]
> Ms. Franklin: Ok, for the rain, you could have a sprinkler or something. And for wind, we could have our own wind with a fan.
> Michael: Ok. That is interesting. It's provocative. So you are saying to simulate wind and rain, with a sprinkler.

Postprogram, Michael's extensive teaching time on bottle rockets (11 days) and his more open approach to students generating their own designs showed he had moved from a more efficient mode of content delivery to one focused more on process.

Renee's students conducted a classic "cookbook" laboratory in the preprogram lesson, and Renee was the one who walked them through the steps. Postprogram, she teamed students, and their questions turned to each other rather than to Renee.

Although all four of the teachers in this study appeared to enact inquiry in somewhat similar ways, there were distinct differences in the four in terms of their long-term plans for inquiry. In interviews with the teachers, Michael and Kaitlin indicated they already had modified lessons (in addition to those designed for the MET) to further incorporate inquiry into their classrooms. In contrast, Renee and Nate discussed inquiry in terms of a discrete inquiry lesson (the lesson designed for the MET). For example, Nate said,

> I'm just going to keep [the lesson] the way [it is] because I think that the students get something out of that... if nothing else it's a nice break... About once every nine weeks we have a period of the week or two where we'll, I'll take a break from my normal mode of teaching which is lectures, book work, ... films... [and waves are] a subject which really lends itself well to this... Refine some of the equipment that we use and things like that to make it a little easier for them.

Contrast this to how Michael described his future plans for inquiry,

> Researcher: It's still August and you've already mentioned FCAT (State exam). So, will you do this one lesson again inquiry based each year? Will there be any other lessons that get affected by it? Just tell me what you're thinking about.
> Michael: Well, for me, I just really can't see any other way of teaching science other than this way, of getting them to ask questions and test [investigate].
> Researcher: Why do you want to get them to ask questions?
> Michael: That's more focused on ownership.
> Researcher: Why do you want student ownership?
> Michael: Oh. Well, it's the only way I know they are thinking about [the material]. Well, it's not the only thing, but it's one of the ways I can tell that [students] are actually thinking about it by the question that they came up with.

What reasons did Nate and Renee give for their adoption of inquiry simply in terms of one added lesson? Nate in particular seemed to position the need to "cover content" as a clear barrier to the use of additional inquiry lessons in his classroom. Although Renee was not as vocal in her dismissal of inquiry as a viable classroom practice, her postprogram period evidenced scant movement toward its incorporation. The literature has many examples of teachers who cite contextual constraints as impediments to use of reform in their teaching (e.g., McRobbie & Tobin, 1995; Muire, 1997; Saka, 2007; Yore et al., 2007). What was puzzling was that Renee and Nate, the teachers who limited their use of inquiry to one lesson designed in the program, seemed to have the fewest contextual impediments to employing inquiry. Both were located at middle to upper middle class schools, with supportive principals, high standardized test scores, and plenty of supplies.

Michael and Kaitlin, on the other hand, both worked at schools rated below average by the state's accountability measures, had very high numbers of low SES (75% and 45% F/RL) and minority students (75% and 79%), and in Michael's case, had difficulty purchasing extra supplies.

Instead, what we see are two teachers, Kaitlin and Michael, who openly worked to modify their practice and closely examined the results of these modifications. We argue that it was this reflective stance, the questioning of their underlying values that occurred during this reflection which seemed to drive these individuals to examine their teaching and to consider the changes they were indeed making (Gregoire, 2003). Using Kegan's (1994) developmental terms, these teachers were changing not only some of their teaching practices but also the way they were thinking about teaching and who they were as teachers. All of the teachers had experienced the same program, all four made some changes to their conceptions of and abilities to enact inquiry, yet only two of the teachers were discussing lasting changes, and their participation in the RET experience did not seem to explain these differences.

Factors Beyond the Research Experience for Teachers Experience

Looking for a viable explanation to account for the different pattern of change in long-term use of inquiry across the four teachers, the first author went back to the data. Two of the teachers, Kaitlin and Michael, used multiple references to educational theory. Upon further investigation, she learned that these two teachers were enrolled in a graduate-level learning theory course immediately prior to their participation in the MET program.

In this course, broad theoretical topics such as cognitive/personal constructivism and social constructivism were introduced along with more specific constructs such as alternative conceptions, assimilation/accommodation, cognitive disequilibrium, and conceptual change theory. Following the exploration of learning theory, specific teaching practices were introduced, including the learning cycle, conceptual change, and inquiry. Alongside each of these ideas, students were introduced to some of the more current and teacher-centered discussions of the nature of science. The students in this class were asked to use these constructs to understand and reframe the learning that occurred in their own science classrooms through interviews with their students after a specific unit. This interview was designed so that the teachers could explore the efficacy of their current teaching practices, and to design a lesson to address students' alternative conceptions via learning cycle, conceptual change, or inquiry approaches. The final unit design required them to employ one or more reform-minded teaching strategy (i.e., learning cycle, conceptual change, and inquiry) and to provide a theoretical rationale for that design. The course readings were clearly linked to science learning and the course assignments required that the theoretical constructs be tested out in the realities of the classroom (contact second author for details of the course).

Upon closer investigation of the class recordings and transcripts of our interviews, multiple utterances from both of these teachers were coded as conceptual change theory and other theoretical constructs. In Michael's case, his theoretical focus was primarily on conceptual change theory (Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1992). Kaitlin's focus was on conceptual change theory and nature of science (McComas, 1998), and her interviews were littered with references to students' background knowledge, misconceptions, process skills, metacognition, and active engagement. In contrast, Nate's preprogram questionnaire had one reference to "inquiry using 'constructivist' methods." Preprogram, there were no theoretical references by Renee, and none postprogram by Renee or by Nate.

In this study, the two teachers with more sophisticated understandings of teaching and learning were far more apt to employ the pedagogy from the MET program throughout their classroom teaching practices than the two teachers with less developed ideas about learning. Engaging in negotiations with the STIR instrument, reflecting on critical incidents, and pondering question analyses with these teachers clearly enhanced the process of reflection with all four teachers. Yet the teachers who were operating out of a relatively sophisticated theoretical framework were more likely to incorporate their MET experience in the broader context of their teaching, seeing the possibilities for student learning throughout their instruction, rather than to view inquiry solely in terms of the addition of one lesson or unit.

Michael and Kaitlin left their graduate course with a heightened awareness of the difficulties of science learning and an expectation that focused attention is needed if students are to restructure the knowledge they bring into the classroom. Their graduate-level course presented a number of reform-minded instructional techniques, each designed to address and meet these learning difficulties and complexities. As such, Michael and Kaitlin entered the MET with knowledge of inquiry as a set of instructional techniques designed to better support student science learning, rather than a stand-alone model of instruction. Michael and Kaitlin had a theoretical frame for learning in which inquiry was seen as a theoretical construct, and they immediately sought ways to incorporate more of what they learned in the MET throughout their teaching.

This more holistic adoption of inquiry contrasted with our observation of the containment of inquiry to single discrete lessons, as seen in Renee and Nate. Clearly both Nate and Renee were able to change their practices in the context of the lesson they developed for the RET and carried out with their students. Indeed, Nate's inquiry-based lesson on waves was a nearly identical model to that of the MET program, and Renee's was a close approximation. What did not occur with these teachers, however, was the incorporation of the inquiry to other aspects of their teaching. Rather than interpreting this in terms of some sort of judgment of these teachers, instead we suggest the findings speak to the requirements for a profound professional development experience.

CONCLUSIONS

The MET program acted to bridge teachers' authoritarian views of science by engaging them in authentic scientific inquiry (Anderson, 2003; Chinn & Malhotra, 2002; NRC, 2000). The four teachers in this study gained an understanding of scientific inquiry through direct research experiences. The case studies of Renee and Kaitlin provide images of what teachers actually were doing following professional development, addressing a call for this in the literature (Marx et al., 2004: Yerrick, 2000). This research also adds credence to the model of teachers at the center of reform (Woodbury & Gess-Newsome, 2002), highlighting the role of teachers' underlying goals, beliefs, and values, corroborating the work of Anderson (2002), Crawford (2007), Kegan (1994), and others. What became clear in this study is that, despite an explicit program focus on reflection, a clear model of scientific inquiry, direct engagement of the teachers, and follow-up that engaged teachers in further reflection on their practices, there still were impediments to teacher change.

We argue that teachers' recognition of the multiple forms of inquiry, the role that knowledge of learning theory, and a familiarity with models of teaching play an important role in their ability to deconstruct inquiry into its essential parts. This knowledge and familiarity allowed two of these teachers to examine a lesson and determine whether an inquiry approach was appropriate and what form of inquiry seemed a "good fit." The teachers were familiar with the essential features of inquiry, and saw these features as useful in student learning. Settlage (2007) discusses the use of these essential features in inquiry teaching, and the ability to modify these features as the content and context dictates, as more realistic and desirable than singular application of open-ended, Level 3 inquiry, as was modeled in the second research project of the MET program. Two of the teachers seemed unable to recognize inquiry as a flexible approach to the teaching of science, and they were not able to recognize how aspects of inquiry might be systematically employed throughout their teaching.

In this research, we asked how teachers' conceptions and enactment of inquiry changed following their participation in a RET, and we saw that for all four of these teachers, they changed to be much more student centered, with a strong focus on students' actively conducting investigations. Yet despite all of the changes in conceptions and enactment we witnessed with these four teachers, we wanted to know whether they were changing in underlying ways that would be lasting (Kegan, 1994). To do this, we examined their thinking, goals, beliefs, and values using critical incidents and prolonged engagement, as well as asking about their future plans (as we were in continued contact with all of these teachers for at least an additional year, these plans are not speculative). What we found was that the differences in teachers' future plans could not be attributed to what had occurred during the RET. Instead, deeper, more substantive rethinking of teaching to an understanding of theory underlying inquiry and student learning took place for two of these teachers prior to the RET experience.

As an example of the differences in the ways these teachers talked about their goals for inquiry, Nate said,

> My goals were very much to try to get the concepts by them of why waves behave the way waves behave and how they were formed, what made them break, you know.

Kaitlin wrote,

> I knew that students brought ideas into the classroom that reflected their cultures and preconceived ideas, but I never considered the degree to which these ideas might affect the incorporation of new knowledge. It wasn't enough for me to tell the students new information. I had to find ways to get them into their schemas in order for them to accept the ideas and find them useful.

Both of these teachers are very interested in student learning, but Kaitlin is engaging at a much more theoretical level in terms of how students learn and what that means in terms of her teaching. She is indicating that she is changing the very way she thinks about teaching and learning. And her engagement with theory through her graduate work seems to have been a critical means for doing so.

The RET that these teachers experienced was a nontraditional model of a RET (Blanchard, Granger, & Gilmer, 2007; Dutrow, 2005), as it incorporated authentic scientific experiences with reflection on the process of inquiry, as well as reflection on how such experiences can be translated to the classroom. This research demonstrates that a RET experience can be transformative for teachers, *if* the teachers come to the experience theoretically ready to learn from them. Yet, there is no silver bullet for inquiry: sustained teacher change following a RET requires teachers to rethink their practice at the deepest level, at the level of teachers' beliefs and values.

Implications for Professional Development

From this we posit that RETs may be more effective if the participants are "primed" to learn from them. In this study, two teachers, unwittingly perhaps, were primed for the inquiry-based experience they encountered at the marine laboratory. Professional developers would be wise to consider preprogram work to similarly prime other teachers for pedagogically based research experiences as a way to get teachers to explore, reflect upon, and revise their own conceptions of teaching and learning. There are examples of programs that have implemented aspects of theory into the professional development experience, and this study further suggests that such inclusions hold the promise of great benefits (e.g., Marx et al., 2004; Roehrig & Luft, 2004).

Certainly, the findings of this study pique our interest on the intersection of theory, reflection, and practice, and how to best combine them with regard to transformative teacher development. Our findings suggest the need for further research to identify the most effective and appropriate way of weaving together theory, reflection, and the research experience to engender teacher change as described by Kegan (1994) and others.

Finally, it is unlikely that we could have gained the level of understanding we did without the many sources of data and the profound and prolonged engagement with these individuals. We argue that it was this methodological rigor that enabled us to paint such detailed portraits of these teachers. Thus, we gained an understanding of the nature of their changes and important lessons on the value of robust and explicit theoretical underpinnings to professional development experiences. Future research into the influence of RETs as well as other professional development experiences should be mindful of this. Research into teacher change requires a sustained and meaningful engagement with teachers. We believe this research also requires multiple data sources at the classroom level to help understand and distinguish between different teachers' inquiry teaching.

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APPENDIX A: INQUIRY QUESTIONNAIRE, PRE/POSTPROGRAM

Participating teachers were required to complete a questionnaire used to describe their conceptions of inquiry:

1. How would you define an inquiry investigation? (Please include the key characteristics.)
2. What aspects of your case study lesson demonstrate the presence of, or absence of, the characteristics of an inquiry investigation?
3. What are the primary learning goals for this investigation?
4. Why have you identified these as the primary learning goals for this investigation?
5. Why is the use of inquiry an appropriate, or inappropriate, approach for addressing your goals for these students?
6. What aspects of your case study lesson demonstrate your specific action(s) to facilitate the characteristics of inquiry to meet your learning goals for these students?
7. Which aspects of the investigation were effective, or ineffective, in terms of reaching your goals with this group of students? Why do you think so?
8. What would you do differently if you had the opportunity to pursue this investigation in the future with a different class?

APPENDIX B: TEACHER/LEARNER INQUIRY CONTINUUM, WITH DATA SAMPLES CODED

	LC	Somewhat LC	Somewhat TC	TC
Inquiry metaphors and definitions	Focus on student learning, hands-on doing, exploration, observations, student-generated questions.	Students take lead on some aspects such as predictions and trying to answer questions. Student prior knowledge and curiosity a focus.	Teacher as facilitator, guided inquiry.	What scientists' do, removed from students, fixed "scientific method."
Content	Connections to real world, ideas are related, connections to students' lives, interactive.	Content involves some student interaction, partially focused on processes, some relevance to students.	Content delivered by teacher, but some student participation, responding to questions.	No examples or interconnections, focused on factual content, delivery, no hand-on content, focus on state standards/tests.
Teacher's actions	Teachers act in support of student learning, actions.	Students encouraged to ask questions, allow students to make mistakes, guide students in their thinking.	Address student questions in discussion, use questions, asks student questions on factual material, monitor students.	Direct instruction, identify misconceptions, monitor behavior, focus students on content.
Assessment	Multiple forms of assessment, some formative; focus on investigation findings and presentations.	Students generate presentations with teacher guidance, mix of factual and investigative knowledge accounting for grade.	Grades for "on task" behavior and for answering teachers' questions, focus is on matching teachers' knowledge.	Tests and quizzes over factual material.
Students' actions	Students actively participate in learning, experimentation, creating questions, etc.	Students assume more responsibility, make predictions, gather data, learn content, use science skills.	Dialogue so teacher can gauge problems, adjust thinking to teacher ideas.	Answer teacher questions, review for a grade.
Other factor(s) mentioned by teacher	Time did not allow for more in-depth student investigations, student interest promotes retention.	Students assumed more responsibility for their learning.	Students thought it was social time, lab took a lot of class time.	Not enough teacher control without handouts.

LC = Learner Centered; TC = Teacher Centered.

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