

Developing an Understanding of Inquiry by Teachers and Graduate Student Scientists through a Collaborative Professional Development Program

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Abstract

The PRISM program partnered K-12 teachers with science and mathematics graduate students who served as Scientists or Mathematicians-in-Residence in the teachers' classrooms. The teachers and graduate students participated in a Summer Inquiry Institute during which they learned about inquiry-based instruction, and then collaborated to develop and co-teach content-rich, inquiry-based instruction in the teachers' classrooms for one academic year. In the first three years of the program, 27 teachers and 18 graduate students participated. The research study examined how participation in PRISM influenced the teachers' and graduate students' conceptions of inquiry, explored what they learned about inquiry by implementing inquiry together in the classroom, and studied the role that their collaboration played in the development of their conceptions of inquiry. Conceptions and use of inquiry were examined through surveys, online journals, interviews and classroom observations. The results indicate that the teachers and graduate students deepened and expanded their understanding of inquiry. Particular themes emerged related to what the teachers and graduate students learned about inquiry through the act of teaching via inquiry were (a) inquiry engages students' minds not just their hands, (b) discussion is essential for student learning, and (c) teachers need to help develop a classroom culture conducive to inquiry in order for students to be successful with inquiry-based learning. This research indicates that teacher-scientist/mathematician partnerships can be beneficial to both parties when structured within a long-term professional development program that immerses the participants in the inquiry process and provides ongoing support.

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Introduction

Inquiry as an instructional approach has been a significant component of recent science education reform efforts (American Association for the Advancement of Science [AAAS], 1993; Barrow, 2006; National Research Council [NRC], 1996a, 2000; Rutherford & Ahlgren, 1990). The National Science Education Standards (NSES) (NRC, 1996a; p. 22) define inquiry as:

A multifaceted activity where students: make observations; pose questions; research in textbooks and other reference materials what is already known; plan and implement investigations; use evidence to explain questions; use tools to gather, collect, and interpret data; propose answers, questions, and predications; and communicate findings.

Subsequent research studies have endeavored to further define inquiry (Anderson, 2002; Crawford, 2000; Newman et al., 2004). Because there are multiple ways to encourage scientific inquiry in the classroom (Bybee, 2000; Martin-Hansen, 2002; Tafoya, Sunal, & Knecht, 1980), inquiry is best represented as a continuum of approaches that employ aspects of inquiry in the NSES definition (Brown, Abell, Demir, & Schmidt, 2006; Eick, Meadows, & Balkcom, 2005; Furtak, 2006; Lee, Buxton, Lewis, & LeRoy, 2006; NRC, 2000).

While science teachers are often aware that inquiry is an approach they should be using in the classroom, individuals' conceptions of inquiry can significantly differ. This is important to consider because teachers' views of inquiry affect their use of inquiry (Wallace & Kang, 2004). For example, a teacher who believes that students are engaged in inquiry when doing a hands-on "cookbook" laboratory may not realize that inquiry can be much more than this. On the other hand, teachers who believe that inquiry only occurs when every aspect of the NSES definition is included in the lesson believe that students are doing inquiry only in a completely open-ended lesson. This leads many teachers to conclude that inquiry is too difficult to do and thus do not attempt inquiry at all (Brown, Abell, Demir, & Schmidt, 2006; Wee, Shepardson, Fast, & Harbor, 2007). Therefore, Keys & Bryan (2001) posit that, "multiple modes of inquiry teaching and learning will invite teachers to engage in participating in inquiry in ways that match their own beliefs and teaching styles" (p. 632), a view that is supported by Blanchard, Southerland, & Granger (2009). In addition, the best choice of inquiry method can depend on many variables, including goals of the lesson, student experience with inquiry, classroom context, and school resources (Settlage, 2007; Songer, Lee, & McDonald, 2003).

Collaboration is important to this process of helping science teachers better understand inquiry and develop their ability to use a range of inquiry approaches in the classroom. In a survey of the research on inquiry teaching, Anderson (2002) emphasized the need for collaboration: "Collaboration is integral not only to the technical dimension of reform endeavors, but to the cultural dimension. ... Collaboration is a powerful stimulus for the reflection which is fundamental to changing beliefs, values and understandings." (p. 9). Collaboration is also important for sustaining change. In a recent study of teachers during and after a summer inquiry workshop, Wee et al. (2007) found

that teachers implemented less inquiry during the academic year than they had planned during the summer workshop. Wee et al. (2007) concluded that support during implementation of inquiry is critical.

Many reform documents have called for the specific collaboration of scientists and mathematicians with K-12 teachers to improve K-12 education (National Commission on Mathematics and Science Teaching for the 21st Century, 2000; NRC, 1996b). Professional development programs have found that pairing a scientist with an educator can create effective facilitation teams for leading K-12 teacher professional development workshops (Czerniak, Beltyukova, Struble, Haney, & Lumpe, 2005; Duran & Ballone Duran, 2005) and can also influence the college-level teaching of the scientists (Ballone, Czerniak, & Haney, 2005). Other researchers have partnered scientists and teachers in the teachers' classrooms to improve inquiry teaching (Caton, Brewer, & Brown, 2000). Scientists in this context, however, usually do not have a background in inquiry-based teaching and often use instructional practices that do not model inquiry (Schuster & Carlsen, 2009). Thus, an effective collaboration between scientists and educators needs to develop both groups' understanding of inquiry in science teaching as well as an awareness of the differences in professional cultures between these two groups (Drayton & Falk, 2006; Nurnberger-Haag, Huziak-Clark, Van Hook, & Ballone Duran, 2008).

The PRISM program, a National Science Foundation (NSF) GK-12 program, fostered year-long collaborations between graduate student scientists and mathematicians and grade 4-12 classroom teachers to support both groups in developing a conception of the entire inquiry continuum, help them learn how to implement effective inquiry strategies in K-12 and university classrooms, and to provide continual support during implementation of inquiry in the teachers' classrooms. The GK-12 program was created to bring together the content expertise of mathematics/science graduate students and teaching experience of K-12 teachers in order to improve the content knowledge of teachers, the communication skills of graduate students, and the science teaching abilities of both groups. To accomplish these goals, PRISM facilitated year-long partnerships between K-12 teachers and graduate students in the role of Scientists or Mathematicians In Residence (hereafter, scientists) in the teachers' classrooms. The scientist-teacher teams participated in an intensive Summer Inquiry Institute and then co-planned and co-taught science and/or mathematics using inquiry for an entire school year (Huziak-Clark, Van Hook, Nurnberger-Haag, & Ballone Duran, 2007; Nurnberger-Haag et al., 2008). The PRISM program and how its participants' understanding of inquiry developed will be described in detail.

Review of Literature

Defining Inquiry Along a Continuum

A continuum of inquiry teaching approaches appears in *Inquiry in the National Science Education Standards* (NRC, 2000), describing varying levels of student self-direction and teacher direction (p. 29). For the purposes of this research, we constructed an expanded inquiry continuum (Figure 1) to frame this study and present to the

participants as part of the Summer Inquiry Institute described in the next section. This inquiry continuum is grounded in the literature of known inquiry practices and shows inquiry in increasing complexity as students have increasing control. The continuum begins with Tafoya, Sunal, & Knechts' (1980) *confirmational inquiry*, defined as an activity assigned to the students for which the main task is to prove what is already known or could be inferred by the students. It continues with *structured inquiry*, for which the teacher provides students with questions, procedures, and information but not the correct or known answer. Next is *guided inquiry*, where students are given a question to answer, but they may or may not have the procedure, or the procedure may be developed as a class (Furtak, 2006). Martin-Hansen (2002) adds two types of inquiry to Tafoya et al.'s descriptions beyond guided inquiry: coupled and open. *Coupled inquiry*, a type of inquiry not given in the continuum of NRC (2000), is a combination of guided inquiry and open-ended inquiry: students begin with a question, investigate the issue, share results and then students engage in open-ended inquiry based on discussions or personal interest. *Open-ended inquiry* is one in which students develop a research question and the procedure or method by which they will answer it, including a data collection plan. The inquiry continuum combines levels of student and teacher participation with inquiry strategies to demonstrate a progression from teacher-centered to student-centered inquiry.

Confirmation → Structured → Guided → Coupled → Open-Ended

Figure 1. Definitions of scientific inquiry of Tafoya et al. (1980) and Martin-Hansen (2002) compiled into one inquiry continuum.

Effect of Inquiry on Student Learning

Several meta-analyses have examined the effect of inquiry-based teaching approaches on student learning (Shymansky, Hedges, & Woodworth, 1990; Shymansky, Kyle, & Alport, 1983; Wise & Okey, 1983). Unfortunately, each study in the analyses used different definitions of inquiry and few studied how inquiry was actually implemented with students. However, despite these difficulties in interpreting the literature, the meta-analyses indicate that research supports inquiry as a pedagogical approach. For example, Shymansky et al. (1983, 1990) found an improvement in achievement, attitude and process skills due to inquiry-based teaching. Recent studies have shown that using inquiry-based teaching methods enhanced 3rd and 4th grade students' abilities with some inquiry tasks (Lee, Buxton, Lewis, & LeRoy, 2006), content achievement and engagement with 8th graders (Lynch, Kuipers, Pyke, & Szesze, 2005), and increased science understanding and inquiry skills for 7th and 8th graders (Geier et al., 2008). In addition, Dean & Kuhn (2006) showed that discovery learning has long-term benefits over direct instruction. While the literature is not uniformly supportive of inquiry

teaching (Furtak, 2006), Anderson (2002, p.4) summarizes: “In general, research shows that inquiry produces positive results.”

Anderson (2007) argues that “Inquiry learning is foundational and essential for a first-rate education” (p. 821), but then warns that not all teaching thought to be inquiry-based results in inquiry learning. For example, Pine et al. (2006) found that while inquiry-based teaching improved student learning, simply adopting inquiry-based curricula was not sufficient, because few of the teachers “went beyond a recipe-like approach to the curricula” (p. 481). Thus using new curricula designed for inquiry still does not guarantee that students will participate in actual inquiry-based activities. Four years earlier, Anderson (2002) noted this same problem, indicating that although the teachers had resources designed to help them teach via inquiry in the form of NSF supported curriculum materials, “Generally speaking, however, the materials were not being used in a manner consistent with this philosophy” (p. 7). Thus, while inquiry can enhance student learning, adopting an inquiry-based curriculum is not sufficient to ensure inquiry in the classroom.

In order to teach effectively using inquiry a teacher must be willing and able to move flexibly between many different roles. Crawford (2000) identified ten such roles that a teacher may adopt as they facilitate inquiry in a classroom: motivator, diagnostician, guide, innovator, experimenter, researcher, modeler, mentor, collaborator, and learner (p. 931-2). In order to fulfill each of these roles a teacher must be comfortable with a variety of teaching strategies (e.g. cooperative learning, discovery learning, problem-based learning) in addition to possessing strong content knowledge.

Barriers to Inquiry

There are a variety of difficulties that educators face when beginning to use inquiry to teach science. Welch, Klopfer, Aikenhead, and Robinson (1981) suggest some common barriers for teachers, the most common being perceived difficulty, especially with classroom management. Many educators did not learn science or mathematics through inquiry methods themselves, so they may feel ill-prepared to teach with inquiry methods (NRC, 2000; Weiss, Pasley, Smith, Banilower, & Heck, 2003). If teachers attempt inquiry, they may see students’ initial confusion and lose confidence in inquiry’s effectiveness. In addition, Brown and Melear (2006) suggest that when teachers learn science via an open-inquiry process, they “often experience a loss of confidence in their science knowledge” (p. 954). This idea can lead to further reasons that teachers avoid or reject inquiry as a teaching method. Finally, there are political and cultural dimensions that must be addressed so that teachers can be supported in their quest for more inquiry based teaching practices (Anderson, 2002; Anderson, 2007). Pressure from administrators or parents who are not familiar or confident with inquiry may lead to a teacher’s decision not to practice it. Teachers may also feel like they have to teach only factual knowledge in order for their students to succeed in standardized proficiency tests.

Statement of the Problem

The NSES (NRC, 1996a) state several standards for effective science teaching. These standards focus on inquiry in the following statements: “teachers of science plan an inquiry-based science program for their students” (p. 30), “focus and support inquiries while interacting with students, orchestrate discourse among students about scientific ideas, [... and] encourage and model the skills of scientific inquiry, as well as the curiosity, openness to new ideas and data, and skepticism that characterize science” (p. 32). Based on the review of literature presented, these standards are difficult and teachers are faced with many barriers to accomplishing these tasks. The PRISM program focused on addressing ways that teachers and scientists, learning, planning, and teaching together could effectively overcome the barriers to implementing inquiry-based teaching methods.

Consequently, we asked three main research questions about the effect the PRISM Summer Inquiry Institute and academic year professional development had on the teachers’ and scientists’ ideas about inquiry:

1. How did participation in PRISM influence the teachers’ and scientists’ conceptions of inquiry?
2. What did the teachers and scientists learn about inquiry by implementing inquiry together in the classroom during the academic year?
3. What role did the collaboration between scientist and teacher play in the development of the teachers’ and scientists’ conceptions of inquiry?

Description of PRISM Program

The PRISM program partnered science and mathematics graduate students (scientists) and K-12 teachers. Over a period of three years a total of 27 teachers and 18 scientists participated in the program. The scientists were graduate students in biology, chemistry, geology, mathematics or physics. The teacher participants had at least three years experience teaching in grades four through twelve. The scientists were recruited for the program from incoming graduate students and current graduate students recommended by faculty as having an interest in education. The teachers and scientists participated together in a Summer Inquiry Institute and then co-taught in the teacher’s classroom for one academic year. The scientists participated for up to two years. In their first year they were partnered with an upper elementary teacher, while in their second year they were usually partnered with a content specific teacher in grades 7-12. The phases of the PRISM program are highlighted in Figure 2. The design components of the PRISM professional development model were purposefully selected and planned based upon research on effective professional development and self-efficacy beliefs from many studies and reports (Fullan, 1982; Haney & Lumpe, 1995; Loucks-Horsley, Hewson, Love, & Stiles, 1998).

Time	Frame	Activities
Phase I	Summer-	Scientists and teachers participate in learning about inquiry, teaching strategies (e.g., 5E model), participate in inquiries along the continuum, and learn from past PRISM teachers and scientists about co-planning and teaching. Begin to plan for the academic year.
Phase II	End of Summer-	Co-plan and develop inquiry-based activities that meet the state and local standards.
Phase III	Academic Year-	Continue to co-plan and co-teach inquiry activities. Monthly professional development meetings to discuss barriers and concerns. Additional support. Academic year observations by external observers.

Figure 2. PRISM program description of activities

Summer Inquiry Institute

Using the inquiry research and guidelines described above, the PRISM faculty designed a five-week Summer Inquiry Institute where science and mathematics graduate students and classroom teachers worked together to learn how to design and implement quality inquiry lessons. Components of the Institute were facilitated by Education faculty, Arts & Science faculty, and PRISM participant teacher-scientist teams from previous years of the program. These role models, describing and modeling inquiry experiences, were key to participant understanding of the challenges and rewards of using inquiry in the classroom (Huziak-Clark et al., 2007).

Scientists and teachers participated in a range of inquiry activities from across the Inquiry Continuum (e.g. Exploratorium foam activity (Exploratorium, 2008), open-ended stream table investigations). The participants' experiences from the activities and the observations they made about the range of inquiry teaching approaches from the different activities fed discussions about the Inquiry Continuum (Figure 1) and effective inquiry-based teaching. During the first three weeks of the Institute, scientists and teachers participated in professional development in which they experienced inquiry-based educational practices such as cooperative learning and contextual teaching and learning (Johnson & Johnson, 1994; Kagan, 1992; Tafoya et al, 1980); learning theory, including learning styles and multiple intelligences (Barba, 1995; Donovan, Bransford, & Pellegrino, 1999); and alignment of curricula with national and state mathematics and science education standards (National Council of Teachers of Mathematics, 2000; National Research Council, 1996a). A learning cycle approach, particularly the 5E model (Bybee, 1997), was emphasized as a useful and effective structure on which to build inquiry lessons (Abraham, 1997). The basic learning cycle employs an exploration phase, an explanation phase, and an extension (or application) phase in this specific sequence (Abraham, 1998) and the 5E model adds an engagement phase at the beginning and an evaluation phase at the end (Bybee, 1997). Critical to the model is that the students explore the topic and then develop the scientific explanation, rather than the traditional approach of providing the explanation and then having the students verify the explanation

(Abraham, 1998). All the lessons and workshops in which participants engaged during the Institute modeled this 5E learning cycle.

In the planning and development phase (the last two weeks of the Institute), the teams applied what they learned about inquiry while working together to develop inquiry-based modules or effectively adapt existing high-quality modules consistent with the recommendations found in the *Ohio Academic Content Standards for Mathematics and Science (Ohio Department of Education, 2003)*. In addition, teams peer-taught one of their lessons to the group for feedback and reflection. Peers and education faculty provided feedback in order to improve the level of inquiry of the lessons before they were implemented with students.

Academic Year Professional Development

The lessons designed during the Summer Inquiry Institute were implemented by the teachers and scientists during the academic year in the teachers' classrooms. In addition, the teams continued to design and implement content-rich inquiry-based lessons throughout the academic year. The teachers and scientists reflected on their experiences with inquiry in online journals and during project meetings in which they could interact with other teachers and scientists. One of these project meetings was a monthly regional professional development event for which participants were assigned methods/tasks to try with their students, complete reflections, and discuss at the next monthly event. Their professional development was further enhanced by presenting inquiry-based lessons they developed to other teachers at several regional science and mathematics education symposia.

Research Design and Instruments

The overall evaluation of the three-year program was extensive and involved a combination of quantitative and qualitative research methods. However, for the purposes of determining how the teacher-scientist pairs learned about inquiry, developed inquiry lesson plans, and implemented these plans, we draw primarily on four main data sources to aid in triangulation of our themes: inquiry methods survey, journal prompts, classroom observations, and focus group interviews.

Inquiry Methods Survey

The Inquiry Methods Survey (see Appendix I) was developed by the authors and is a pre/post survey where participants were asked to define inquiry, describe a sample lesson, and describe possible barriers to teaching via inquiry methods. The authors established content validity by having the survey reviewed by five other science educators familiar with inquiry teaching methods and barriers. Modifications were made based on the reviews of the content specialists. The survey has 12 open-ended response questions to determine the state of a participant's ideas, attitudes, and concerns about teaching by using inquiry-based teaching methods. The teachers and scientists completed the survey at the beginning of the Summer Inquiry Institute and at the final academic year project meeting. Three researchers read and tallied the responses of the survey to

determine pre/post changes. We compared our coding of the responses to check for internal consistency and did so with more than 90% agreement.

Journal prompts

Each participant was asked to respond to online journal prompts once or twice a month. Many of these journal prompts directly related to inquiry-based teaching and learning in the classroom. The journal prompts were a combination of open-ended questions to encourage the teachers and scientists to reflect as well to ask specific questions needed for reporting to the funding agency. For example, one journal prompt asked teachers and scientists individually to “describe a lesson that you co-taught this week and describe how you employed inquiry during this lesson.” Questions like this were used to probe the participants’ concept of inquiry and to assess the types of inquiry activities being implemented by the teams.

Classroom Observations

Classroom observations were conducted by the PRISM faculty and staff with science and education expertise. In addition, three times a year, teams were formally observed by an experienced educator who was not a member of the PRISM team. The observers used the Horizon’s Classroom Observation Protocol (Horizon Research, Inc., 2000a), the design of which was funded by the National Science Foundation to “measure the quality of an observed K-12 science or mathematics lesson” (Horizon Research, Inc., 2000b). This protocol focuses the evaluation on four main areas: lesson design, implementation, science/mathematics content, and classroom culture. Information from these observations was used to provide objective feedback to the teams as well as to document the level of inquiry teaching during the academic year. Formal comments on the teams’ progress and use of inquiry served as an additional way to document the successes and challenges of teaching via inquiry.

Interviews

The teachers and scientists participated in structured individual or focus group interviews at the end of each academic year (Fontana & Frey, 2000). In focus group interviews, participants were grouped as teachers or scientists separately to allow for honest reflection. The interview (see Appendix II) consisted of 16 structured interview questions and was run by the project internal evaluator or one of the evaluator’s graduate assistants. The same protocol was used for both individual and focus group interviews, and in the focus groups the participants were given an opportunity to respond to each question individually. The interviews were tape-recorded, transcribed, and coded.

Data Analyses

The journal prompt responses, interview responses, and Horizon reports for all of the participants were analyzed using a grounded theory perspective (Charmaz, 2000; Erickson, 1986; Glaser & Strauss, 1967). To identify emergent themes and assess the use of reflective thinking within the data, three readers of the research team independently reviewed the journal prompts, interview transcripts and Horizon reports. From iterative

readings of the journal prompts and evidence, initial codes were subsumed under broad categories (Erickson, 1986). For example, each of the research members noted several themes throughout the journal prompts, surveys, interviews and classroom observations. These themes included inquiry teaching, collaboration, student achievement, and enthusiasm about teaching science. The focus of this paper is from the theme of inquiry teaching. After discussing these specific themes and the examples that all three agreed on, the group determined “sub themes” or specific codes and specifically defined and agreed to meanings of each code (Glaser & Strauss, 1967). For instance, “inquiry engages minds, not just hands,” was decided on as a sub-theme under teaching with inquiry. The research team agreed that there were a breadth of respondents who reported they recognized the importance of discussions for inquiry teaching, the need to develop a classroom culture for inquiry, and that inquiry engages minds, not just hands. The theme of inquiry is the umbrella for each of these important ideas. Again, the research team revisited the data and recoded with these categories or codes in mind (Erikson, 1986). These categories were used in further iterations of data readings by the researchers, who met to negotiate and clarify the themes and their meanings. Once this was accomplished, data that fit each of the themes were coded with that category and later used to elaborate on findings in this study. The research team agreed that in order to establish “fit” all three readers had to agree that the data met the operational definition. Miles & Huberman (1994), refer to this as “an organized assembly of information that permits conclusion drawing and action taking” (p. 11). By using the grounded perspective the researchers were able to triangulate meaning from multiple sources, (interview, observation, and journal entry) so that we were able to “accurately describe what [we] understood, constructing recognizable reality for the people who have participated in the study” (Maykut & Morehouse, 1994, p. 122). The findings and conclusions, drawn from the categories, will be explained in subsequent sections.

Findings

Several important themes were evident in the survey, interviews, journals and classroom observation. These themes detail the changing notions and, more importantly, the practice of teachers and future Arts & Science faculty and instructors towards inquiry as a way of teaching. These themes were: viewing inquiry as a continuum, realizing that inquiry engages students’ minds not just their hands, discovering the importance of discussions, and needing to develop a classroom culture that supports inquiry. We document each theme with the inquiry survey, teacher and scientist journals, and interviews and classroom observations as appropriate.

Seeing the Inquiry Continuum

The participants formally reflected on what inquiry meant to them several times during the year in the inquiry surveys and in their journals.

Initial conceptions of inquiry. The teachers and scientists commonly used several key phrases during the pre-inquiry survey. For example, the majority of the participants included the idea of hands-on activities as part of their notion of inquiry. Half of the participants included questions as a key component of inquiry.

The following quotations from teachers are typical of responses on the first day of the Summer Inquiry Institute and depict teachers' early notions of inquiry (NB: All names are pseudonyms. T after the name indicates a teacher; S indicates a scientist):

Learning through inquiry is student directed. The students determine the topic of study, method of presentation, and the steps needed to complete the project. The role of the teacher is to guide and move the team in the right direction without giving too much information. (Mike-T)

Learning is more student lead and less teacher lead. The students have more control over what they are experimenting with and why. (Marjorie-T)

I would define learning through inquiry as a technique that can be used to help some students. This technique involves the student seeking the answers to questions instead of simply being told the answer. (Herman-T)

The teachers hold that inquiry is student driven and, upon further discussion, most believed that students have to be involved in individual or group projects instead of a class investigation for it to be considered inquiry. Thus, the teachers mostly began with an understanding of inquiry as primarily open-ended, placing their conception of inquiry at the right end of the Inquiry Continuum (see Figure 1). Their understanding does not reflect the flexibility of inquiry-based teaching methods described in the review of literature. Teachers' use of a strictly open-ended conception of inquiry instruction was itself a barrier to doing inquiry in their classrooms. By helping teachers recognize that inquiry can take many forms across the continuum, we help them bridge the gap between the position on the continuum where most teachers' lessons would be classified and the open-ended region of the inquiry continuum. In this way teachers can see how they can move themselves and their students toward the open-ended portion of the continuum. In this way they find validation at the other points along the continuum knowing that they now have the skills and understanding to facilitate inquiry-learning at multiple degrees and that open-ended inquiry is not always the best method for accomplishing particular learning goals.

The scientists had little to no formal education in pedagogy, so their ideas about teaching math and science stemmed largely from their experiences as students in undergraduate content courses or their K-12 school experiences. The following early scientists' notions of inquiry from the highlight their thinking at the start of the Summer Inquiry Institute:

Giving students examples and having them come up with the definitions and methods. (Jacob-S)

Teachers asking questions to spark discussions. (Ralf-S)

By asking questions to discover the individual answer, or solution to a given problem. (Ruth-S)

Note that the scientists' initial ideas are mainly focused on the teacher, not the students. These ideas about inquiry mostly sit near the left end of the Inquiry Continuum (Figure 1) and are, for the most part, different than those of the teachers.

Conceptions of inquiry one year later. As the quotations above illustrated, the scientist initial views of inquiry tended to reflect the confirmation side of the continuum as being representative of inquiry, while the K-12 teachers often viewed only very open-ended learning as inquiry. In the post inquiry survey, after participating in the Summer Inquiry Institute and collaborating with their partner to implement inquiry in the classroom for the academic year, most of the participants expanded their conceptions of inquiry to cover a larger band of the Inquiry Continuum. As one teacher, Barbara, expressed it during her end-of-year interview,

I'm trying to apply what I learned just like the kids apply what they learned, but then I try to go back and reflect on that and see how can I make it more inquiry based, or is this an appropriate level, and what lesson fits in where with the inquiry continuum and all that stuff. (Barbara-T) (Huziak-Clark et al., 2007)

The following post inquiry survey quotations provide examples of these post notions of inquiry for teachers:

Learning through inquiry is when students are responsible for their own learning. It is when a question (either student or teacher generated) is posed to the student and it is up to the student to determine the answer. That answers are then compared to the rest of the class and as a large group the result are discussed to determine the results of the lab. It is this discussion of lab results that drives the student learning. (Mike-T)

Learning through inquiry is a global approach for the students. Inquiry brings together background knowledge, reading, writing, and working together to solve or answer questions one has about science or any other topic. (Chelsea-T)

One significant change in the teachers' ideas of inquiry was the idea that inquiry is a communal effort by the class, not just by individuals. This is an important change in beliefs that can lead to changes in practice. Teachers' prior beliefs that every student had to do their own project for it to be inquiry could be a daunting notion for even experienced teachers. In addition, inquiry without student-student interactions ignores the critical role that social interactions provide in developing understanding. Being able to view inquiry as something that a class can contribute to and work on collaboratively is an important shift. In addition, the collaborative nature of this instruction reinforces that scientists often work in teams.

The scientists' understanding of inquiry also changed over time through working with the teachers and by participating in the Summer Inquiry Institute. For example, Taylor provided the following conception of inquiry in the post inquiry survey:

Learning through inquiry involves the students discovering concepts on their own through minds-on and hands-on experiences. Inquiry does not necessarily have to be a hands-on experience. The only requirement is that the student has ownership in his/her development. (Taylor-S)

This idea marks a shift from primarily teacher-centered conceptions of inquiry that the scientists held to a more student-centered conception of inquiry. Like Taylor, Ruth's conception also showed a shift towards thinking about what the students do, not just what the teacher does:

Presenting the students with a hands-on science experiment, and asking questions that require them to think deeper about the experiment. Also, having the students explain to each other what they think is happening and why! (Ruth-S)

In addition, notice how Ruth's conception of inquiry now includes the core idea that inquiry can be a group/class endeavor, one of the shifts noted earlier for the teachers.

The above examples provide a view of the teachers' and scientists' notions of inquiry from the inquiry survey. The teachers and scientists also reflected about inquiry in their journals:

Inquiry means three things to me: discussion, critical thinking, and hands-on. The discussion can be taking place between teacher and students or students and students. [...] There is no doubt that it would be easier as a teacher to simply tell or lecture the information to the students because it takes less time. However, I do believe students get more out of an inquiry lesson than a lecture lesson. Students feel a sense of accomplishment by "figuring something out for themselves." (Ralf-S)

The cooperative learning strategies have provided my lessons with a more structured and constructivist approach. The 5E learning model reminds me to value student questioning and to build lessons around big ideas. During my science lessons, I am no longer in the front of the classroom. Rather, I am facilitating small groups of young scientists, while posing problems of relevance. (Tracy-T)

The change here from the initial survey is a more holistic approach to inquiry. More of the teachers and scientists see inquiry as a way of thinking about teaching than just a pedagogical technique. From the quotations shown, one can note the shift to an emphasis on the cognitive aspects of an inquiry-based lesson, the importance of questioning and discussions, and the need for specific skills for students to do inquiry. Each of these themes is expanded upon below.

Inquiry Engages Students' Minds Not Just Their Hands

Although hands-on activities are often a key element in inquiry-based lessons, they are neither always necessary nor sufficient by themselves. A clear theme in the

classroom observations, journal prompts, the survey, and interviews was that participants developed an understanding that inquiry is more than just hands-on activities. Before the Summer Inquiry Institute many participants initially believed that having students complete an activity about the content was sufficient for students to learn the content. Through a year of co-planning and co-teaching, the participants recognized that teaching by inquiry requires engaging the students' minds, not just their hands. Below a scientist describes tweaking his partner teacher's existing hands-on lesson to add an inquiry component:

We have started our weather unit that [teacher partner] and I worked on this summer. Our first few lessons have been on the nature of air. Each of our lessons on air has begun with a "challenge" to the students. Our first challenge was for [the students] to get air into a submerged, overturned cup without taking it out of the water or turning it over. The only tool they could use to get air in the cup was a smaller cup. At first many of the students thought the task was impossible however they all dove-in with enthusiasm. After a little bit of trial and error they hit upon the solution of holding the smaller cup upside down so air stayed in it until they got it under the larger cup and then turn it over so the air would go into the larger cup. The students then discussed in their groups what this showed about air (i.e. air takes up space). [Teacher partner] said that she had done this lesson previously but that in the past she had demonstrated to the students the solution beforehand. She said that those students had thought the lesson was neat, but that this one really got the students involved and made them think (Chester-S).

Both the teacher and scientist realized that even though a hands-on component was already present, making the lesson more inquiry-based required getting the students mentally engaged in the content of the activity. Collaboration with the scientist was critical in helping the teacher make this change since the scientist encouraged the teacher to let the students figure out the solutions on their own and then provided support during the lesson. Many of the scientists discussed their efforts of promoting student thinking in their journals. For example, a scientist described his experience with a spaghetti tower construction project early in the school year:

The students came to me for assistance when their tower designs did not materialize in the manner they had hoped. Naturally, what the students wanted was for me to tell them what was wrong with their designs and to do X to fix problem Y. Just as naturally this was not something I was going to do. I tried to direct their attention in a critical manner toward their towers, asking them to identify the problem/weakness in their structure and then think about how they might address the problem/weakness. [...] My goal was not the success or failure of the tower but to lead the students through the process of analytical thought and problem solving. (Mark-S)

A month later, the same scientist commented in his journal,

Now that the students have a few design activities under their belts (both successful, and perhaps more importantly unsuccessful) their approach is completely different. [...] Many students are now looking to identify the cause of problems in their racers and not simply disassembling and rebuilding during the problem-solving phase. There are even a few students whose racers incorporate genuinely surprising and completely functional design elements. (Mark-S)

Notice that now with these hands-on activities the scientists are focused on the mental processes of the students, and work with the students to develop these processes further. The teachers echo the scientists in their journals and in interviews about their PRISM experiences.

[PRISM has] helped fine-tune me too. Now I can do hands-on with the best of them, but it's not always inquiry. And that's the difference. So now I'm learning how to put the inquiry in the whole package. As opposed to just the experiment part. (Chelsea-T)

I am enjoying the inquiry teaching, but am having to hold myself back from giving the answers rather than letting them DISCOVER on their own! It was really neat seeing the students get excited about learning and asking their own questions and finding their own answers. (Valerie-T)

The teachers are each explaining that they previously did hands-on activities; however, now due to their experiences in the Summer Inquiry Institute and their collaboration with the scientists, they are reevaluating the methods they use, how they present these laboratory experiences, and how these hands-on activities are now just one aspect of a more developed lesson. The teachers realized that just because a lesson involved a lab or a hands-on activity did not always mean that the lesson was inquiry-based. They have begun to realize that, as Songer, Lee, and McDonald (2003) wrote, "Inquiry is more about substance than form" and that it is the "quality of intellectual engagement among students" that is a critical factor in inquiry (p. 514).

Importance of Discussions to Learning Via Inquiry

As the participants began to realize the importance of student thinking in inquiry, they also began to recognize that in order to foster true student learning, they needed to change their planning in order to make more time for discussions and "sense-making" of the content. For example, a major difference between teacher Mike's pre- and post-survey notions of inquiry is his recognition of the importance of discussion in the post-survey, which concludes with, "It is this discussion of lab results that drives the student learning."

A common theme in the journal responses, the interviews and the surveys is the importance of discussion and sharing ideas for students to learn from the inquiry process. Many teachers and scientists began to realize that they could engage their students in inquiry by facilitating a rich discussion about the topic first. Not only did it get the

students motivated and interested, it also helped the teacher understand what the students already knew. As one teacher (Elinor) explained in the end-of-year teacher focus group,

You always have to begin with the questions. You always have to have a question that you can manage and change, and so I got that now. And the more I can have my kids think about a question and then begin what they want to do with that question. That's the goal. (Elinor-T)

The critical importance of the class discussion during the explanation phase of the 5E learning cycle was new to many of the participants. In particular, the participants realized that the explanation should draw from the students' observations and ideas in the context of a discussion about the topic. In one of her journal entries, a scientist described how discussions are the difference between doing inquiry and just doing an activity:

I believe two classes could do the exact same lab activity, and depending on how it is approached and discussed determines whether it is an inquiry-based lab or just an activity. I think understanding the process of asking questions to lead the students to the information and not just dumping the information on them is the key. [...] The more you can get teachers to understand the importance of a good discussion, and get them to feel totally comfortable leading one, the better inquiry-based labs you'll have going on in the classroom. (Kerstin-S)

Another teacher described how a lesson now flows in her classroom. Notice she now understands the purpose of the explanation phase in the 5E learning cycle. For this teacher, *explain* is no longer synonymous with teacher lecture or exposition. Students and/or teachers can participate in doing the explaining as long as the necessary connections and clarifications are made to tie the lesson together.

Students record observations and then do group discussions to talk about their observations. Then the groups make small presentations about their findings. During these discussions a lot of the Explain comes out. Students have questions about why certain things happened so it leads into the explanation quite easily. (Gertrude-T)

The scientist (Peter) who co-taught with Gertrude described one of these class discussions:

Unifying the results of the class and drawing conclusions was very tricky. One group disagreed with the rest of the class in their results, so we watched them demonstrate the experiment. It was great – the class ripped their misconceptions to threads. Once we had a consensus, we could look at some theoretical applications of Bernoulli's Principle. (Peter-S)

These quotations illustrate how the participants viewed class discussions, including student presentations and peer review, as a vital mechanism for sense-making by the students. They believed that these discussions were critical for clarifying student ideas and correcting their misconceptions. Notice also that the starting point of the

explain phase was the students' observations, ideas, and experimental results. The participants drew upon the students' own data to lead to the students to a concept, rather than just telling the students what to think. Teachers discussed how their students had noticed the change:

The students in my classes have come to realize that lab is not just something you get through to say, "Ok we finished that now let's move on." They realize there is a valuable lesson to be learned from doing the lab. (Mike-T)

I have found out that the students need to bring concepts to a close. They really get into discussions and want to take things to the next level. (Kelly-T)

Notice the importance described by both participants that just completing the activity is not enough. They both recognized that students will learn more if they are provided the time to discuss and process the material in groups and as a class. In Kelly's case, her comment at the end of the year showed a major shift in her thinking since Gertrude, the scientist with whom Kelly worked, had set a goal for the year of helping Kelly recognize the importance of using discussions after hands-on activities instead of just moving on to the next lesson. Mike's partnering scientist also promoted expanded post-lab discussions throughout the year, which were emphasized in both of Mike's previous comments. The scientists also gained a greater appreciation for the role of discussions for learning at the university level. Jacob described how he taught a university mathematics course while involved in the PRISM project:

[It] has been interesting to see how my approach to teaching has changed. A few weeks ago I covered a section on transforming the graphs of functions. ... When I got to class, I was surprised at how I was teaching. Instead of lecturing, I was having a conversation with the class. I would ask the students questions, and then take the students answers and comments and get us to where we needed to be. ... As I was teaching, I found myself thinking more about what the students had to say, than what I wanted to say. I was interested in allowing them to lead the discussion and have the class learn from what they had previously seen. (Jacob-S)

The external reviewers also noted the use of good discussions and questioning that was evident in teams' planning and implementation:

The design reflected careful planning and organization and allowed adequate time and structure for sense making for the students. [...] The activities led to an in-depth discussion that allowed Julian [the teacher] to recognize the level of understanding of his students. This was prompted by Julian asking higher-order questions about his students' responses to the brainstorming wheel. (Paula-observer)

Through the use of discussions students were able to use mathematical reasoning and justification of ideas. By working collaboratively as a class, students were able to constructively challenge each others' ideas. The activities in the lesson encouraged investigation of questions and providing justification for answers. (Sheila-observer)

These comments further demonstrate the value the participants felt discussions played in teaching the lessons via inquiry. In addition, these reports support the implementation of the participants' planning into practice.

Developing A Classroom Culture That Supports Inquiry

Finally, many of the teachers and scientists found that their students were prepared to complete "cookbook" laboratory activities, but when it came to implementing more inquiry-based lessons, many skills such as questioning and working in groups needed to be developed and enhanced. In journal posts, teachers discussed the classroom culture required for student success.

Children need to have good questioning skills in order to perform inquiry-based lessons. They also have to be able to use higher level thinking, and they need the confidence to know that they are able to do this. (Melissa-T)

Several of the teachers commented on this culture-building problem as one of the initial barriers to inquiry for them in the past. As one teacher described her situation at the beginning of the year in her journal:

Our fourth grade students need a lot of skills that they don't necessarily have to participate in inquiry lessons. The biggest problem I've experienced is with the kids that don't know how to work in cooperative groups. In our school they don't do a lot of that in third grade so when they get to fourth grade it can sometimes be a tough adjustment. Once we learn how to work in groups, it gets a lot easier. (Kate-T)

Another teacher described similar concerns and discussed in her journal how inquiry actually helps develop these skills, rather than viewing these skills as a prerequisite barrier to beginning to teach via inquiry.

[My partner scientist] and I have been working on improving the students' cooperative learning skills and increasing their collaboration. This goal is coming along very nicely. Inquiry-based lessons actually help them develop these skills. On Thursday, we will get a better idea of how well the students can use these skills. The lesson will be at a higher level (less structure) of inquiry. (Increasing the level of inquiry has also been a goal of ours.) They will be required to do more problem-solving and reasoning. (Carie-T)

Both teachers and scientists noted the initial difficulty students can have with inquiry since it differs from traditional school instruction:

When we PRISM fellows come into the classroom with our inquiry-based teaching we put the students out of their element. Both traditionally successful and unsuccessful students can resist inquiry because it's different from the school thing they've been doing for the past 12-13 years. By starting off with easier inquiry lessons and practicing inquiry we can smooth the initial resistance and build up a confidence and comfort with a new technique for learning. (Mark-S)

Note how Mark is thinking in terms of the Inquiry Continuum (Figure 1) in gradually moving his students from the teacher-directed end of the continuum to more open-ended forms of inquiry.

It was not just the PRISM participants who needed support in changing to an inquiry-based way of learning. Participants noted that students are used to teachers emphasizing the importance of the final answer. Consequently, participants reported that students recognized a change in the classroom culture from the way they were used to learning to a culture of inquiry learning. Students recognized a shift in emphasis from obtaining results or answers to the process of learning. For example, one scientist, Eddie, noted in his journal,

[W]e have to spend a fair amount of time in the Explain stage and often have to remind kids to think about what they already know. It might seem strange, but we often have to remind our kids to stop and think as they just want to get to an answer and move on. (Eddie-S)

Similarly, a teacher described in an interview how he worked with the students to value the process of learning, not just getting the final answer:

Kids instead of just writing and listening they're actually having some experiences with trial and error, they can participate. I told my students it was the hardest thing, it'll be hard for you too because your whole life you've done it this way: here's some notes, here's what you're supposed to find, do it. [... The students] were saying, "Man, I had to think so much with this." Absolutely, that's what I want. That's actually another thing I have learned – the kids have been trained to do it this other way so you have to get them used to doing it as well. To not being told exactly what they're supposed to find, but it's okay to mess up and not do things right and to learn from it. (Julian-T)

Because this shift to inquiry can be a significant culture change for students, many participants discussed the motivational aspects of inquiry, in particular the need to build the students' confidence in their ability to do inquiry. For example, scientist Marius observed that,

For the students to succeed in inquiry, I feel that they need to be encouraged enough to believe that they can find answers on their own. They still need guidance, but the confidence in themselves will get them

very far on their own. The more they attempt on their own the more they will get out of the lessons. (Marius-S)

In addition, students need to feel comfortable discussing ideas. Scientist Ralf suggested that a classroom culture for discussion is needed for inquiry learning to take place.

I think the biggest and simplest aspect for our students to succeed in inquiry is having them feel comfortable and confident in discussing their thoughts and opinions in science. Tracy does a great job in creating this atmosphere in the classroom. (Ralf-S)

Not only is it necessary to facilitate discussions, but, as the quotation above described, it is important for students to feel safe and that they have a voice in the discussion. It is not only the job of the teacher to discuss, but of the whole class community to participate in discourse. The scientists were learning from the teachers how to establish classroom cultures that can support inquiry.

The Horizons Observation protocol explicitly examines classroom culture and the external evaluators noted a classroom culture for inquiry as a strength for many of the teams. For example, Paula said this about one team: “there was a climate of respect for students’ ideas, questions and contributions. Interactions between teachers and students reflected collaborative working relationships.” Dawn stated it in a slightly different way: “There was a climate of respect and the teachers had an awareness of what was going on in the classroom and whether or not more information was needed at any given time. The climate of the lesson provided opportunities for students to brainstorm, make conjectures, and ask questions in a safe environment conducive to learning.”

There are many factors that were important to making inquiry successful in each of the team’s classrooms. As a strategy new to many students, the teachers and scientists needed to facilitate the students’ transition to inquiry-based learning through developing inquiry skills, building students’ confidence, and, perhaps most difficult, changing the mindset of the students – so that ambiguity and making mistakes are acceptable and getting to the “right” answer is not the most important goal of the lesson.

These changes in the teachers’ and scientists’ understanding of inquiry did not occur immediately, or even by the end of the Summer Inquiry Institute. In their journals throughout the year they would share new revelations or understandings about inquiry. This was particularly true for the scientists since inquiry teaching was a newer concept to them than to the teachers. Tina (scientist) reported in February of her first year, “suddenly realizing what PRISM has been trying to teach me all along. I really finally internalized the idea of inquiry!” Another scientist (Mark) described in his journal in May at the end of the year his journey with inquiry:

During the summer session I remember being highly skeptical of this 'inquiry thing'. I was afraid we were being peddled the latest and greatest development in science education practice, absolutely guaranteed to make

your students 75% smarter, cut gender/socioeconomic achievement differences, and cure male pattern baldness in the class hamster. ... By the end of the summer session I figured that there might be something to this 'inquiry thing' in theory, but I still wasn't sure that we could make it work in the classroom. ... [A]s the year progressed we tried many ambitious lessons using inquiry as the vehicle to deliver content. Some were successful, others less so. We became more confident in our ability to use inquiry as a tool to deliver content material and make the lessons succeed with greater frequency. ...

In the last couple of weeks [teacher partner] and I have been running our pond water investigation with the students. This is the most ambitious open inquiry we have done all year. The students are given a sample of pond water and challenged to design an investigation to learn something about it. For the first couple of days the students really struggled with this inquiry. ... After a few days of grinding through this frustration the student have begun picking things up. They're beginning to put the pieces together. You can see the wheels starting to turn and the student's creativity starting to show. The students are starting to get excited about things they are discovering in the pond water.

The epiphany? Inquiry isn't about experiments. It's not about leading the students to a bit of content knowledge, nor is it about learning a process. Inquiry is about using thought to fight through a wall of 'not understanding', breaking through and turning around to finding a door was there the whole time. (Mark-S)

Limitations of Study

The inquiry survey, journals, and end-of-year interviews are data reported by the participants themselves, though the external observers' reports are consistent with the self-report data. Many factors affect changes in a classroom environment and we cannot isolate the effect of just the PRISM program on the teachers. In addition, we cannot completely separate out the effects of the Summer Inquiry Institute and academic year meetings from the effects of the co-teaching collaborations. Finally, the teachers in the study were generally those who seek out professional development opportunities and the graduate student scientists went through a rigorous application process that also probed their interest in K-12 education. Thus, the participants were not a random cross-section of teachers or graduate students. Yet, it is interesting to note that precisely despite being experienced educators who seek to improve their practice, their initial concepts of inquiry were quite limited and for the most part untried with students until the PRISM program.

Conclusions

Participation in the year-long PRISM professional development program led to changes in teachers' and graduate student scientists' notions and attitudes about using

inquiry teaching. Based on the research questions investigated, we drew several conclusions.

First, how did participation in PRISM influence the teachers' and scientists' conceptions and use of inquiry? The teachers expanded their understanding of inquiry beyond open inquiry, which they had rarely used, to the full continuum of inquiry approaches. From the teachers' journals, interviews and classroom observations, it is clear that teachers were learning to use inquiry across the continuum and were beginning to implement it effectively in their classrooms. Success in overcoming some of the barriers to inquiry will likely make them more willing to try new inquiry lessons. In the interviews at the end of the year, the teachers stated that they would continue to build on those lessons developed with the graduate student scientist or mathematician. As was noted by the scientists in journals, interviews and in classroom observations, there has been a change in their thinking about inquiry teaching, too. They have expanded their understanding of inquiry from the teacher-centered end of the continuum to the entire continuum and have begun to see its value for teaching, even at the university level.

Second, what did the teachers and scientists learn about inquiry by implementing inquiry together in the classroom during the academic year? The participants developed an appreciation for the importance of both the cognitive and social aspects of inquiry. They recognized that hands-on activities alone do not constitute inquiry; rather, inquiry engages students' minds, whether it is confirmation, structured, guided, coupled, or open-ended inquiry. They learned that discussions are critical to student learning via inquiry. They realized that discussions can be used throughout the learning cycle – to engage the students' thinking at the beginning of the lesson or to allow for sense-making by the class after an activity. Finally, they discovered that inquiry requires a classroom culture that promotes investigation and discussion by making students comfortable to ask questions, express and challenge their ideas, and make mistakes. These changes in the teachers' and scientists' understandings of inquiry did not occur immediately, but over the course of the year, as illustrated, for example, by the teachers Kelly and Mike in learning the importance of discussions, and by scientist Mark's journal of his inquiry journey.

Third, what role did the collaboration between scientist and teacher play in the development in the teachers' and scientists' conceptions of inquiry? The partnership was a critical component of the change in the teachers and scientists. In their journals and interviews, scientists and teachers often talked about the importance of their partner. For the teachers, it provided a partner who would provide continual support and feedback during implementation, an important part of teacher implementation of inquiry as discussed in the literature review. In addition, collaboration with a content expert provided the teachers confidence to attempt more open forms of inquiry, as illustrated by the example of Chester and the air lessons described earlier in Findings. Partnership with classroom teachers provided the scientists an opportunity to explore inquiry teaching in an environment where they had support from experienced educators who could establish classroom cultures appropriate for inquiry. Also, the teacher and scientists were able to identify areas in which they could improve and then work together to effect change. The example of Kerstin and her success in helping Kelly learn to use discussions highlights the value of these collaborations.

Implications

Evidence from this study suggests that the collaborative opportunities afforded by the PRISM program expanded and clarified the teachers' and scientists' notions about inquiry. The following implications can be drawn from this study:

Extensive and long-term scientist/mathematician-teacher collaborations facilitated by professional development in inquiry-based teaching can be an effective way to change conceptions about inquiry and to promote inquiry-based teaching in K-12 classrooms.

The Scientist/Mathematician-in-Residence and K-12 teacher partnership was a critical component of the PRISM professional development model. The partnership allowed each partner to employ inquiry with the constant support and feedback of another professional. Each partner brought to the team complementary strengths that were critical in overcoming barriers to implementing inquiry. In addition, the collaboration held both partners accountable for implementing inquiry, thus ensuring that teachers and scientists had the opportunity to learn by using inquiry. Finally, collaboration allowed joint reflection and continual feedback for improving both partners' pedagogical skills.

Positively influencing teacher and scientist notions about inquiry-based teaching requires time and experience using inquiry, and is aided by a support structure that encourages the use of inquiry and reflection about the use of inquiry.

The Summer Inquiry Institute provided the teachers and scientists with experiences using a variety of inquiry approaches and provided a foundation for the academic year. It was the intensive, year-long teacher-scientist collaboration, however, that helped them experience inquiry in their own classroom and see its effect on the students. This success in the classroom reinforced what they learned in the Institute and addressed their doubts about inquiry. The participants described changes in their understanding of inquiry due to their experiences in the classroom, even late in the academic year. Having a collaborator in planning and teaching, as well as reporting regularly to the project staff through journals and in project meetings, provided the participants a support structure that encouraged using inquiry and reflecting on their experiences.

Directions for Future Research

This study suggests several areas of future research about scientist-teacher collaborations to enhance inquiry-based teaching. First, do the teachers continue to use the inquiry lessons they have developed with the scientists and grow in their use of the inquiry approach, or do they use less inquiry over time without the continued support of the scientists and the PRISM program? Second, how do the scientists who become higher education faculty employ inquiry in their higher education classes? Are they able to translate their understanding of inquiry teaching from a K-12 setting to a higher education setting? Third, in what ways do the scientists collaborate in formal or informal

ways with K-12 teachers later in their career? Fourth, how could this model be employed with Ph.D. scientists instead of graduate students in a realistic manner? For example, could a K-12 collaboration sabbatical program be created to facilitate higher education faculty to serve as scientists in residence at a K-12 school. Finally, what is the effect on the K-12 students' attitudes towards science and a career in science from having a scientist in residence in their classroom for a year?

A vision of science teaching and learning promoted by many reform documents calls for science and mathematics classrooms to become active and inquiry-based environments. The lessons learned by PRISM provide an insight into a model of professional development that supports the participants in pushing through the barriers to teaching using inquiry. The experiences explained here are also unique because there is a true collaboration between classroom teachers and graduate student scientist/mathematicians, with both parties developing knowledge about inquiry-based teaching and learning. If we expect this type of teaching to occur in future science classrooms, it is important that as researchers we recognize and document the time, effort, professional development, and university support necessary to aid classroom teachers and future university science and mathematics faculty in the art of inquiry-based teaching and learning.

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Appendix I: Inquiry Survey (Teacher Version)

1. How would you define learning through inquiry?
2. Describe a lesson where inquiry-teaching methods are being used.
3. What skills do students need to have in order to do inquiry?
4. What skills do teachers need to have in order to teach using inquiry?
5. Describe a classroom environment conducive to inquiry
6. How often did you use inquiry in your classroom this past year? (Example: Once a week, twice a week, once a month, once a quarter)
7. What do you see as the advantage of teaching for inquiry during the upcoming academic year in your classroom?
8. What do you see as the disadvantages of teaching for inquiry during the upcoming academic year in your classroom?
9. Are there any people or groups who would approve or disapprove of your teaching for inquiry during the upcoming academic year in your classroom?
10. What things would encourage you or make it easier for you to teach for inquiry during the upcoming academic year in your classroom?
11. What things would discourage you or make it harder for you to teach for inquiry during the upcoming academic year in your classroom?
12. Do you have any other thoughts or concerns about teaching for inquiry during the upcoming academic year in your classroom?

For the graduate student scientists, questions 7-12 asked about “a future college classroom” instead of “the upcoming academic year in your classroom”.

Appendix II: Graduate Student Scientist Interview Protocol

1. Describe your past K-12 science and math experiences, How did these experiences affect your career plans?
2. Describe your collaboration with your teacher partner—when did you go to the school, when did you plan, how did you plan, how did you implement the plans in your classroom?
3. How has your participation in PRISM impacted your opinion of K-12 science or math? (Follow up—Has your attitude towards teaching and learning science or math in K-12 changed? How or why?)
4. Has your PRISM experience made you want to be more involved in K-12 outreach in your future career?
5. Have your teaching or communication skills improved due to your work as a PRISM Fellow? (Follow up – In what ways have your teaching/communication skills improved?)
6. Has your understanding of math and/or science education improved due to your work as a PRISM Fellow? Please explain.
7. How will you transfer the PRISM teaching experiences into the college setting one day?
8. What were the most important things you learned from your teacher partner? How do you think this will transfer into the college teaching environment?
9. Describe an inquiry lesson that you and your teacher partner taught. What did you learn from this experience?
10. What are your career plans? How has PRISM affected these plans, if at all?
11. Do you believe that your teacher partner has gained the tools necessary to do inquiry in his/her classroom?
12. Do you believe that your teacher partner has gained a greater understanding of math/science and a greater confidence in his/her math/science knowledge?
13. Do you believe that your teacher partner will be able to continue using the lessons and techniques that you developed together next year when you are no longer in his/her classroom?
14. Did you perceive a change in the students over the course of the term (e.g., changes in enthusiasm, interest, confidence)?

15. What effect have you had on the school outside your teacher partner's classroom? For example, what effect do you feel you have had on other teachers, an administrator, etc?
16. Did you have any experiences or learn/synthesize material in the K12 classroom or in preparing exercises for K12 students that benefited your research program or academic studies? If so, please give examples. Did your placement require you to teach topics that were not in your discipline? How did that affect you and your own understanding of science/mathematics?