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Chemistry Teachers' Emerging Expertise in Inquiry Teaching: The Effect of a Professional Development Model on Beliefs and Practice

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Abstract This study investigates the beliefs and practices of seven high school chemistry teachers as a result of their participation in a year-long inquiry professional development (PD) project. An analysis of oral interviews, written reflections, and in-class observations were used to determine the extent to which the PD affected the teachers' beliefs and practice. The data indicated that the teachers developed more complete conceptions of classroom inquiry, valued a "phenomena first" approach to scientific investigations, and viewed inquiry approaches as helpful for facilitating improved student thinking. Analysis of classroom observations with the Reformed Teaching Observation Protocol indicated that features of the PD were observed in the teachers' practice during the academic year follow-up. Implications for effective science teacher professional development models are discussed.

Keywords Professional development · Science education reform · Teacher beliefs · Inquiry instruction · Theory to practice

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Introduction

Both national and state standards and international documents emphasize inquiry as the primary approach for teaching science (Abd-El-Khalick et al. 2004; American Association for the Advancement of Science 1993; National Research Council 1996; South Carolina Department of Education 2005). According to the *National Science Education Standards* (*NSES*; NRC 1996), "scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (p. 23). The *NSES* separate inquiry into full and partial inquiries based on the inclusion of five essential features (NRC 2000). According to the *NSES*, full inquiries contain all five essential features which include having students create their own "scientifically oriented questions," "give priority to evidence in responding to questions," "formulate explanations from evidence," "connect explanations to scientific knowledge," and "communicate and justify explanations" (NRC 2000, p. 29). Partial inquiries rely on more teacher direction in one or more of these categories. Even with this emphasis, an inquiry climate is far from the norm in most science classrooms (Weiss et al. 2003). Weiss et al. (2003) found that only 2% of the grade 9–12 classroom lessons observed had a focus on scientific inquiry and only 18% of the classroom lessons portrayed math and science as investigative disciplines in the United States. van Driel et al. (2001) asserted that the emphasis of science teaching is "on lectures to convey science content, and technical training for acquiring practical skills" (p. 138). If a shift from didactic practice towards an inquiry-based approach is to be achieved, effective training must address the obstacles that classroom teachers face such as their beliefs about teaching and learning, their science content knowledge, and previous modeling by their instructors (Crawford 1999).

Effective professional development (PD) may enable teachers to overcome their constraints to using inquiry while at the same time providing them with resources and collegial support (Loucks-Horsley et al. 2003; Luft 2001). However, inquiry professional development experiences do not always lead to changes in teacher practices that are aligned with reform documents (Caton et al. 2000; Luft 2001; NRC 1996; Wee et al. 2007). The success of various inquiry professional development programs depends on their length, content, and format (Huffman et al. 2003; Loucks-Horsley et al. 2003), as well as the beliefs and abilities that teachers bring into the program (Luft 2001; Wallace and Kang 2004; Yerrick et al. 1997). This study investigated the impact of a yearlong inquiry professional development program on the beliefs and inquiry instructional practices of seven high school chemistry teachers using in-depth interviews and the Reformed Teaching Observation Protocol (RTOP; Sawada et al. 2002). Findings from the implementation of this professional development model and implications for future inquiry professional development are discussed.

Literature Review

Influence of Teacher Beliefs on Professional Development

Loucks-Horsley et al. (2003) outlined principles of effective professional development which included having a clear image of effective classroom practices, providing opportunities for teachers to build their content and pedagogical content knowledge, providing time for teachers to reflect on their practice, immersing teachers in research based learning approaches that they can use with their students, forming collaborative communities, and focusing on student learning data (p. 44). In addition to following the principles above, professional development must account for the influence of teachers' beliefs (Darling-Hammond and Ball 1998; Keys and Bryan 2001; Pajares 1992; Yerrick et al. 1997). Teachers often combine their previous beliefs about teaching and learning with the reform strategies introduced in professional development programs leading to a filtering of the information and little change in their teaching and understanding of reform-based practices (Thompson and Zeuli 1999; Yerrick et al. 1997). Roehrig and Luft (2004) detailed the effects of an inquiry-based professional development model for chemistry teachers during their first year of teaching. Of the ten teachers studied, only five were categorized as having practices consistent with inquiry approaches, and only one used inquiry teaching practices on a regular basis. The authors concluded that the teachers' deep understanding of science content and inquiry strategies was a necessary, but not sufficient characteristic for their enactment of the lessons. Instead, the teachers' beliefs about the nature of science and their understanding of their role in the classroom influenced their adherence to reform-based practices.

Others described how teachers' beliefs about science, their students, learning, and the purpose of education all influence whether reform-based practices are used in teachers' classrooms (Lotter et al. 2007; Roehrig and Kruse 2005; Wallace and Kang 2004). Many studies have described how teachers who hold more positivistic, transmission-oriented views of science resist reform-based instruction and professional development (Brickhouse 1990; Hashweh 1996; Tsai 2007; Yerrick et al. 1997). Roehrig and Kruse (2005) found that chemistry teachers with more traditional beliefs about teaching and learning showed the least amount of change in their implementation of a reform-based chemistry curriculum. Wallace and Kang (2004) compiled a set of belief profiles for six secondary science teachers showing that although they all believed that inquiry was an effective instructional strategy (e.g., fostered independent thinking in their students), their use of inquiry varied due to the influence of a conflicting belief set focused on their classroom culture (e.g., preparing students for tests, beliefs about their students' abilities, need to transmit knowledge). Wallace and Kang emphasized the need to make teachers' conflicting beliefs explicit during inquiry professional development programs.

Thompson and Zeuli (1999) argued that effective professional development must create "cognitive dissonance" in the participating teachers in order to change their pre-existing beliefs and practices. They argued that teachers must be given time to work through this change with discussions, readings, writings, and other activities that make their beliefs more concrete and revisable. Teachers also need to be provided with different ways to change their practice and support during the actual change process in their own classrooms. Mezirow (1990) and Loughran (2002) suggested that cognitive dissonance is a necessary step in helping teachers engage in the 'critical reflection' that can result in the decision to redefine their role in the classroom. Microteaching, in which teachers practice teach to each other, and in-classroom practicum teaching experiences (i.e., student teaching) have been used extensively in preservice teacher programs to help beginning teachers acquire new instructional skills (Wideen et al. 1998). Professional development programs for inservice teachers may focus on having teachers observe and learn from other teachers in the same professional development program (Fernandez 2002) or observe demonstration or "expert" teachers' instruction (e.g., Luft 2001) during the school year. Less common is the integration of practice teaching opportunities with students in a non-threatening environment (e.g., summer enrichment program) during the initial professional development training (Lotter et al. 2009; Singer and Maher 2007). Practice teaching has been shown to provide the necessary scaffolding for teachers to transfer workshop strategies to their own classrooms in the middle school professional development program upon which this workshop is modeled (Singer and LaCross 2005). Thus, an important component of the professional development described in this paper is the integration of a practice teaching component into the summer professional development workshop in which teachers are given time to teach, reflect on, and revise their instruction before they enact the reform strategies with their "real" students during the academic year.

If a change in practice is to occur, the change effort must address teachers' beliefs that are in opposition with the reform goals, improve teacher content knowledge, and provide opportunities for teachers to reflect in collaborative communities. This study seeks to understand how a professional development experience produced changes in teachers' beliefs about teaching and learning in the secondary chemistry classroom.

Research Questions

The purpose of this study was to determine the influence an inquiry professional development program had on chemistry teachers' beliefs and use of inquiry-based teaching practices. This study set out to answer the following research questions:

1. Was the professional development model effective in moving the teachers toward a more reform-based understanding of inquiry?
2. What elements of the professional development model did the teachers find to be the most influential to their implementation of inquiry instruction?
3. Were the instructional approaches advocated in the professional development model reflected in the teachers' inquiry instruction as measured with the RTOP?

Participants

The participants in the professional development program were 23 high school science teachers (16 Female, 7 Male). The teachers came from five local school districts and 11 different high schools. All but one participant was from four high-need school districts in which more than 20% of the student population was living in poverty (U.S. Census data).

For this study, the seven teachers in the chemistry teacher cohort were investigated to determine the influence of the PD on their beliefs and classroom enactment of inquiry science lessons. The chemistry teachers' demographic and school characteristics are given in Table 1. This subgroup was a good representation of the program's teacher population with regard to teaching experience, sex ratio (5 F, 2 M), and race [1 African American, 6 White (2 foreign exchange teachers)]. This subgroup also was chosen to study because the chemistry instructor consistently modeled inquiry in the chemistry content sessions throughout the 2-week institute.

Professional Development Model

The professional development consisted of a 2-week summer institute and academic year support. The summer institute was divided into four main segments over the 2-week period (7 h a day for 10 days): whole group inquiry instruction through hands-on activities and discussion, small group content instruction, practice teaching with high school students, and whole and small group reflection sessions. The following sections briefly describe the four sessions that made up the summer institute.

Inquiry Pedagogy Sessions

The summer institute began each morning with the teacher participants spending between 90 (first week) and 40 (second week) minutes participating in inquiry-based activities and discussions about the nature of science. "Appendix 1" provides a description of the morning pedagogy session topics and activities. An explicit

Table 1 Demographic information on chemistry teacher cohort

Teacher	Years of teaching	Race (country of exchange)	Highest education degree	School characteristics: percent of students scoring basic or below basic[a] (%)
Sam	7	White	Masters	26.3
Heidi	8	White	B.S.	33.5
Jill	13	White (India)	Masters	62.3
Karen	23	Black	Masters	53.4
Kevin	15	White	Masters	55.4
Allison	13	White	B.S.	33.5
Mary	2	White (Romania)	B.S.	56.9

[a] Scores from 2006 State Science NCLB test

discussion of how the activity related to the five essential features of inquiry (NRC 1996) was completed after the lesson.

Content Sessions

The participants were divided into four small (5–7 teachers) content area groups (electricity and magnetism, chemistry, forces and motion, and evolution) for content instruction. Due to the study's focus on the chemistry teacher cohort, the structure of this content session is described in detail.

In the first week of the chemistry content sessions, the seven teachers were immersed in chemistry inquiry experiences as students. During this 5-day sequence, the college instructor (CI), with earned graduate degrees in science education (M.Ed.) and chemistry (Ph.D.), national board certification, and 7 years of high school chemistry teaching experience, led the group through chemistry content lessons that illustrated and highlighted fundamental ideas outlined in the teachers' state standards (e.g., chemical change, conservation of matter, thermodynamics, kinetic-molecular theory). In each lesson, the instructor consistently modeled the Predict–Observe–Explain (POE) learning cycle approach to achieve two primary goals: (a) to encourage the teachers' concept acquisition and development and (b) to demonstrate the potential of inquiry teaching to engage students in meaningful and educative science experiences (Gunstone and White 1981; White and Gunstone 1992). The Predict, Observe, Explain (POE) protocol is an instructional approach that seeks to activate students' prior knowledge through guided-inquiry experiences in a 3-step sequence that was introduced by Gunstone and White (1981) and further in White and Gunstone (1992). In the professional development design of the current project, the POE protocol was used as an instructional bridge to help move the chemistry teachers from more traditional instructional techniques to more inquiry-based techniques. It is able to serve as a bridge because it combines more traditional techniques (e.g., teacher-developed questions, teacher provided experimental procedures) with those consistent with recent reform efforts (e.g., prior knowledge assessment, active learning experiences, student investigation prior to formal instruction, and student-driven explanations). The strategy often uses discrepant events to encourage the onset of cognitive dissonance. Through the discrepant event, participants are often confronted with the reality that their initial conceptions do not match with the observed outcomes of common science phenomena. The instructor can then construct other experiences so that the participants' alternate conceptions can become more scientifically accurate (Linn and Eylon 2006). As modeled in the current professional development program, the POE protocol aligned to a partial inquiry (NRC 1996) in that it allowed the participants to use evidence from an experiment or observation to answer a teacher provided question, develop explanations from the experiment or observation evidence, connect their explanations to scientific knowledge aligned to the state content standards, and communicate and justify their explanations. The POE protocol did not allow students to initially design their own scientific questions, but the initial experiments often led to new questions that were explored during the professional development program.

Practice Teaching with Students

During the second week, the chemistry teachers practice taught their own, newly developed inquiry lessons to high school level Upward Bound students participating in a summer enrichment program. Twenty-five rising eighth through twelfth graders from one of the partnering school districts participated in the program. Upward Bound students are selected for the precollege support program based on their financial need, motivation to be the first in their family to attend college, and their drive to be successful in school.

Each content group taught four 90-min classes during the second week of the summer workshop to small groups of students. The chemistry teachers divided the 90-min period into 2 distinct 45-min classes with only one instructor. The content and pedagogy experts assisted the teachers in the development of these lessons making sure the lesson content was accurate and incorporated the inquiry-based strategies advocated by the professional development team.

Reflection

During the summer institute, the teachers spent time evaluating and reflecting on videotapes of their own practice teaching sessions as well as the videotaped instruction of the workshop facilitators (both content and pedagogy instructors). The reflection sessions began as whole group sessions led by the pedagogy instructors and focused on positive exemplars as well as missed opportunities regarding specific pedagogical strategies seen in the videotaped lessons. After the practice teaching began, the teachers reflected within their small content groups on their own instruction to the Upward Bound students. In addition to the video reflection, the teachers completed daily written reflections and a final reflection that focused on the four main components of the workshop: (a) inquiry pedagogy, (b) content instruction, (c) practice teaching/planning, and (d) video reflection.

Methods

This study used a phenomenological approach to determine the influence of a professional development program on chemistry teachers' beliefs and inquiry-based practices. A phenomenological approach allows researchers to understand and interpret meaning within and through contextualized experiences and through individual's own words (Bogdan and Biklen 1998). Thus, to ascertain the chemistry teachers' beliefs about inquiry and their intentions to incorporate inquiry practices, the teachers' own voices were the main data source as heard through three sets of interviews (before and after the summer workshop and at the end of the academic year). In addition to the interviews, the teachers' daily written reflections and final written reflection on the summer program were investigated to determine the teachers' views of the workshop components and practices. Finally, the teachers had their classroom implementation of inquiry videotaped and evaluated using the RTOP (Sawada et al. 2002).

Teachers' Beliefs

The seven teachers were interviewed before and after the summer workshop and again at the end of the academic year using a semi-structured interview protocol ("Appendix 2"). The interviews lasted from 30 to 60 min and were audio taped and transcribed. The interviews were used to ascertain the teachers' beliefs about inquiry, effective teaching and student learning, and the impact of the professional development on their science teaching. The teachers' wrote daily written reflection on the content sessions and the pedagogy sessions (morning session and practice teaching) during the summer workshop.

The first two authors independently coded all written data sources (transcribed interviews and written reflections) for themes related to the research questions using a constant comparative method (Bogdan and Biklen 1998). The themes were compared across time and across data sources (interview transcripts, daily reflections, final reflections) to determine their validity in representing the findings. Themes were modified or new themes were then developed to account for all the data variance. The authors then discussed the separately developed themes until consensus on the data findings were reached. Finally, the researchers developed written profiles for each of the teachers that summarized the themes articulated in the interviews and reflections. Written profiles were multiple page narratives that described through themes and embedded teacher quotes each teacher's beliefs about inquiry, teaching, and learning and their stated instructional changes across the professional development period (Table 2).

Table 2 Timeline of professional development elements that facilitated change in teacher beliefs and research components

PD and research components	Elements	Time
Pre-interview	Semi-structured interview protocol	May, prior to institute
Summer institute		
Morning pedagogy	Inquiry-based lessons and explicit nature of science instruction: teachers participate as students	Week 1: 1.5 h (daily)
Content session	Chemistry content instruction: POE (guided inquiry) model, cognitive dissonance	Week 1: 3.5 h (daily) Week 2: 2.5 h (daily)
Practice teaching	Teachers team teach to high school students	Week 2: 1.5 h (daily)
Reflection	Collaborative and video-based reflection of practice teaching and morning pedagogy sessions	Week 1–2: 1 h (daily)
Post-interview	Semi-structured interview protocol	Last day of institute
Academic year follow-up		
Saturday workshops	Inquiry-based content lessons, videotape analysis of classroom instruction, lesson sharing	Nine held September through May
Classroom observations	Taped observations of teachers' inquiry instruction	September through May: varied by teacher
End of year interview	Semi-structured interview Protocol	May, at last workshop

Teacher Inquiry Practice

To determine the extent to which the chemistry teachers carried out reform-based practices in their classrooms during the year following the summer institute, classroom-based observations were carried out using the RTOP (Sawada et al. 2002). The teachers invited the researchers into their classrooms to tape when they were implementing inquiry activities. They were asked to implement one workshop lesson and one inquiry lesson of their own creation. A total of 12 lessons, two by each teacher except for Sam and Mary (one each), were scored by two independent raters. Classroom observation data were limited to these two observations, thus the researchers can only discuss whether the teachers were able to implement inquiry practices, not whether the practices became a typical part of their instruction.

The RTOP is a 25-question observation protocol that contains three scales (5 questions on lesson design and implementation, 10 questions on content, and 10 questions on classroom culture), that allow researchers to rate a teacher's degree of reformed teaching using a 0 (never occurred) to 4 (very descriptive) scale (Pilburn et al. 2000). The instrument sums to a total of 100 points; however, a score over 50 is considered to be indicative of a reformed-based lesson (MacIsaac and Falconer 2002). Sawada et al. (2002) provide reliability evidence through a Cronbach alpha value of .97 for the entire instrument and validity evidence through factor analysis and expert content analysis (p. 249). In the current study, two raters independently watched and scored each classroom videotape and then consensus was reached between the two different observers (that had been previously trained on the instrument) before a final score was recorded.

Results

Question #1: Was the Professional Development Model Effective in Moving the Teachers Toward a More Reform-Based Understanding of Inquiry?

Initial Teacher Beliefs

As described in the literature review, teachers' initial beliefs about teaching, learning, and science often influence the effectiveness of a professional development program (Lotter et al. 2007). The following section outlines the pattern of beliefs and barriers that the chemistry teacher participants had about inquiry when they entered our professional development program.

As determined through the teacher interviews, the seven teachers entered the program with differing beliefs and conceptions, some of which acted as potential barriers to their use of inquiry instruction. Before the workshop, the teachers' lacked a clear understanding of inquiry pedagogy and therefore lacked a model for how to make inquiry-based changes to their instruction. Conversely, the teachers all felt dissatisfaction, to differing degrees, with their current teaching and the resulting student learning and motivation. This dissatisfaction seemed to provide the initial motivation the teachers needed to make reform-based changes to their instruction.

Incomplete Conceptions of Inquiry Teaching Six of the seven teachers came to the professional development program with some naïve conceptions about inquiry-based teaching. Five of the seven teachers held the conception that inquiry meant hands-on activities or student role-plays driven by teacher questions. For example, in her pre-program interview Heidi described an element tug of war with students acting as elements with different electronegativity values as an example of how she used inquiry in her classroom prior to the summer institute. Jill described the following as an inquiry lesson before the workshop; "I showed them diapers and asked them, 'What are polymers?', and then we acted it out, and stuff like that so that they really knew what it was all about." Jill described inquiry as a teacher demonstration and teacher-led discussion with limited student participation and role-playing. Mary described her students building models of atoms as an inquiry lesson. Mary stated, "I'm giving them all kinds of games and they need to build the atom with the levels of energy and with electrons around." Allison also described a hands-on activity as inquiry in her pre-workshop interview. She said, "I just had them to try to imagine what the world would be like without friction. I had them do a few demonstrations with rubber gloves with hand lotion on, so they couldn't pick things up."

Only Kevin, Sam, and Karen described any type of data analysis or data manipulation in their initial conceptions of inquiry. Kevin described an acid–base titration lab, his only implemented inquiry experiment, in which he had his students make a prediction, collect and analyze data, and explain their findings. Sam equated inquiry with long term student-directed projects that required multiple days to complete. He described doing only one previous mixture separation inquiry laboratory in his classroom due to his incomplete understanding of inquiry. Karen, who had the most informed conception of inquiry before the workshop, described a Christmas tree light lab in which students "explored the relationship between resistance, voltage, and current" that she had used in a previous year.

No Model for How to Change Before the workshop, five of the seven teachers described student learning beliefs that were aligned with the workshops' constructivist framework. These teachers stated that they believed that students learned science best when learning for themselves through teacher guided hands-on activities. For example, Allison said that students "need to learn it for themselves as opposed to just accepting what is written down or what is told to them." Along these same lines, Mary stated that students learn science best "by seeing it and by hands-on activities; that's the most important part because whenever you lecture or talk, until they see it or feel it, they don't understand it."

Despite these constructivist conceptions of how students should learn, the teachers described their classroom environments with very teacher-centered instructional practices and occasional cookbook laboratories. Kevin described how "inquiry is more to augment the other things that you're doing. Chemistry is an applied math course, so you have to learn the math and you have to learn the vocabulary, so what I actually prefer to do is to teach a concept and then have the students do something to utilize that concept." Thus, the teachers' conceptions of how students should learn did not always align with their instructional choices.

Many of the teachers lacked an effective instructional model that would allow them to teach in this ideal manner and still cover their content standards in the time they had available with their students. Allison stated in the end of year interview that before the workshop, "I didn't know quite enough to try it and was always scared that I might not cover everything and someone's going to come in and say 'what are you doing letting these kids just do whatever they want to do' and I was worried about the appearance more than anything else."

Dissatisfied with Current Teaching Practice All seven of the chemistry teachers voiced dissatisfaction with their current teaching and/or their students learning and motivation from their instruction. These teachers described how their students often lacked the ability to make connections between the content standards and cookbook laboratory activities. Kevin described his students' performance on final tests as inadequate because, "so many times I think that they've got it nailed in class and they do well on the quizzes and they did the lab perfectly and then they just couldn't do it on the test and they didn't make the connections." The teachers also described lowered student motivation during their current instruction. Mary described how she wanted to find more ways to help students learn and connect with the standards. Even Allison, who did not discuss dissatisfaction with her teaching, described how she wanted to learn additional strategies to make her teaching easier and help students learn more.

Final Teacher Beliefs

The chemistry teachers were interviewed after the workshop and again at the end of the year to determine changes in their beliefs about inquiry, teaching and learning. Through their participation in the professional development program, the teachers described how they acquired a more complete understanding of inquiry teaching, how they valued the use of the POE model that put phenomena before teacher didactic instruction, and how their use of inquiry increased their students' ability to think critically.

More Complete Inquiry Conceptions In the post-workshop interviews, the teachers discussed how the CI's modeling of inquiry helped them to realize that their initial conceptions of inquiry were limited. For example, Heidi stated that before the workshop "what I thought I was doing as scientific inquiry was not true scientific inquiry. And the questioning and letting the kids think and just the whole process was learned, for the inquiry process really opened my eyes as to what true inquiry means." Mary stated, "The most meaningful experience for me was …the moment when I realized what really inquiry means, because I think everyone of us, we thought that we are doing inquiry, but we realized that we didn't."

The teachers began to redefine what inquiry teaching looked like, incorporating more of the essential features described in the *NSES* and those emphasized during the inquiry professional development (NRC 1996). In the post-workshop and end of the year interviews, many of the teachers described inquiry in terms of the POE model that was demonstrated during both the pedagogy and content sessions. Allison stated in the post-workshop interview that inquiry is "a process as much as an attitude; letting the students make their observations, getting them to think about what might happen and then have them question why it happened?" Jill in the end of year interview stated, "That's what I meant by saying inquiry-based: predict, explain where it was mostly open-ended, predict it and then explain it." Jill went on further to describe her use of the POE model in her teaching of typical inquiry lessons. She stated:

> A typical inquiry day would be that we start with something that I show them and then I ask them to predict, then I ask them to explain it. I ask them to explain everything though. Why their prediction was wrong, or why their prediction could be right, so that they have to explore and …I ended up with a little bit of explanation to what I was seeking of them, what I wanted them to learn…but I also told them that this is just the basics. That one more question they had, they could always throw it to each other and try to resolve it.

Karen in the post-workshop interview stated, "Inquiry to me is active learning. It's active learning through observing, predicting, testing and drawing conclusions."

Phenomena First The teachers stressed the importance of using an experience or "phenomena first" approach to get their students thinking about the content. The teachers that valued the POE approach described the importance of student discussion and explanation of concepts instead of teacher telling. Jill described in her end of year interview how she:

> …used to spell out everything I knew to the kids. I never expected them to know anything, I kind of brought out everything I knew and wanted them to learn it as such, right. I think after I went to the inquiry course, I felt that kids could do a lot more than me, different aspects, and I could make them come out…. I could see them asking me more questions; there were questions that I didn't know the answer, or which we had to find out working together again. That was interesting, I was kind of learning from the kids and they were learning from me.

Karen, during the post-workshop interview described how she should have done more phenomena first in her practice teaching lesson on polymers. She described how, "At the beginning of my lesson I stated some content and I might have given them a little too much content in the beginning and basically I'm going to start off [in my own classroom] by letting them explore and make their bouncy balls and then kind of come back to the content." Mary described how for the practice teaching she had changed a cookbook laboratory assessment into an inquiry lesson in which she made students "write their observation…think by predicting what's going to happen and after that…write down some kind of reasoning after the observations." Kevin at the end of the year stated:

> Well you get results, with the before inquiry, 'BI', there basically, it was a laundry list for the kids to do; they recorded colors, etc. and there really wasn't any science being taught…[now] they're learning the science process…they're actually writing down the results with somewhat being eager

> and they're drawing their own conclusions. So the science skills that they're learning are infinitely greater than what we were learning before.

Question #2: What Elements of the Professional Development Model Did the Teachers Find to be the Most Influential to Their Implementation of Inquiry Instruction?

All seven teachers implemented the inquiry-based practices modeled during the workshop in their classrooms during the academic year. Despite their initial beliefs and practices, the professional development experience motivated the teachers to attempt this new instructional strategy with their students. The teachers identified several components of the professional development model as leading to changes in their practice including a need to experience their own content cognitive dissonance as inquiry learners, the importance of the use of a guided model of inquiry (POE model in this workshop), and the value of having time to practice teach and reflect on that practice teaching with other chemistry teachers.

Content Dissonance

The teachers needed to experience cognitive dissonance about their own content knowledge in order to appreciate the knowledge-generating role of inquiry teaching. The teachers' questioning of their science content knowledge came only after their experiences with inquiry as "students" during the chemistry content sessions. Before the workshop, several of the teachers stated that their chemistry content understanding was strong and that they only needed help with inquiry teaching. This changed after the teachers were pushed during the content sessions to explain their predictions to the rest of the chemistry teachers. For example, Jill described in the post-workshop interview:

> I always thought that I was rich in content and I just needed to change my way of teaching, make it more interesting, but I realized that if you teach through inquiry, the first thing you need to do is know a lot of the content. I mean it's not just one thing that you are looking at, you have to connect and when you make connections you might not be sure of your content…basically me coming from India, you know, being in a situation where I memorized stuff, when I feel I know everything and when it comes to looking at things and trying to really give explanations, I'm like…gosh, I need to brush up.

Heidi stated after the workshop, "I think that was something real powerful that we all saw, because we all said, we are fine with our content, you know, we don't really need help with the content we just need inquiry. But once we started doing the inquiry we realized maybe we don't know as much as we need to know about our content because we really had to think."

The content lessons provided the impetus to assist the teachers to work through their own content misconceptions and think deeply about their explanations for the observed phenomena. The act of writing out their predictions and sharing these with their peers helped to move them toward greater content understanding. When describing her initial erroneous prediction about an experiment in which an air-filled balloon was cooled in liquid nitrogen, Karen stated, “But we could see a liquid in that balloon, and a lot of us said, foolishly enough, that the liquid contained water and with the liquid nitrogen being about 77 Kelvin, there is no way that could be liquid water. That water would be frozen”. Her struggle with the content made her empathize with her students’ learning process and further value inquiry teaching. Heidi described how listening to the teachers’ predictions and explanations during the workshop helped her recognize her and her peers content misconceptions and that a similar strategy could be used in her classroom to understand all the conceptions held by her high school students. She stated:

> What I’ve learned through this is, with all the knowledge that everybody in our group had, as we were really thinking through these different phenomenon we all had different predictions and explanations as to what was going to happen and listening to everybody’s predictions and explanations led us to what was going on and without being able to experience everybody’s thoughts you’re not addressing all the misconceptions.

Sam stated in the post-workshop interview that writing predictions “got more fluid as we went on….we actually had to write down something, get it down, rather than polarizing and shortening, having whole thoughts, backing up, going forward with it, catching yourself and going, ‘oh wait a min, that doesn’t work’, you know, that sort of lesson.” Thus, the teachers had to experience their own initial discomfort with not having all the answers to understand that they could build deeper knowledge together through their shared inquiry experiences.

POE Inquiry Model

As described earlier, teachers often believe that inquiry teaching strategies require more time than they believe they have available to cover their standards (Tobin and McRobbie 1996). During the summer institute, the teachers found the CI’s use of the POE model to be an effective and efficient way to teach in-depth content. The teachers found the POE model to be effective in two different contexts: (a) with themselves in the student role as they worked through the activities during the first week and (b) with the Upward Bound students during the practice teaching sessions during the second week of the summer institute. The use of one consistent model throughout the workshop that reinforced the essential features of inquiry seemed to increase the teachers’ confidence with guided inquiry approaches to instruction. As with any instructional model such as POE, teachers needed to adapt it to their specific context and to the particular lessons they were enacting. For instance, if the students’ prior knowledge relative to the concept being investigated, the prediction phase could be lengthened to allow students to justify their predictions more thoroughly than in cases where they could not articulate a well-defined rationale for their choices. Even though the POE approach as originally proposed in the early 1990s was not used intact by either the professional developers or the teachers, it still served as a simple and effective bridge between the traditional didactic practices and the reform-based pedagogies advocated during this PD experience.

By the end of the 2-week chemistry content sessions, over 20 inquiry-based lessons, aligned with the teachers' state standards, had been enacted, discussed, and reflected upon in detail. Although the satisfaction in acquiring new lessons for their classrooms was implicit in the teachers' interview responses, the more explicit message was that they had all discovered an inquiry instructional model that was considerably different and significantly more powerful than what they had previously been using in their classrooms. Allison stated that the POE process "was very effective in making people, myself, or the students think about what might happen and the next thing is actually seeing what's going to happen and seeing if there is any discrepancy or the differences why." Heidi stated that "In many classes I've taken in the past my instructors talk about teaching, but we don't actually use any of the strategies and neither does the instructor. We did inquiry the entire 2 weeks. I feel I now have a fairly good understanding of how to teach through inquiry. I am comfortable with it and I will use it in my classroom."

After the workshop and again at the end of the year, all of the teachers discussed how the presented inquiry model illustrated how they could teach their content standards and still use inquiry-based instructional practices. The teachers described how the content instructor modeled how each simple inquiry lesson could be used to teach multiple standards. At the end of the year, Mary stated, "I think you can get at least five concepts out of one lab if you know how to direct them and guide them toward the questions." Karen described in the end of year interview that "I've been able to make less more; in the lab activities I've been able to teach through inquiry… I've learned that I could hit many of state standards through one lab and not to have the labs be specific for one standard." Others stated that they had removed many of their long cookbook laboratories and replaced these with multiple short POE activities that allowed their students to wrestle with many different content standards in the same amount of time. Sam stated at the end of the year that, "I do more short labs, short inquiry kind of things… and I probably do fewer of the regular procedures out of the book…so it's changed that way, a lot and to the better, I really do think to the better. It's actually a time saver."

Practice Teaching and Self-Reflection

The teachers' practice teaching and reflection on their own teaching provided the impetus for change. Analysis of the post-workshop interview transcripts and written reflections indicated that the teachers assigned significant value to this practice teaching experience as it related to their willingness to enact inquiry lessons with their own students. It seems that although the instructor-led content lessons were powerful in driving their *own* conceptual change, at least some of the teachers needed to see that the inquiry instructional approach was effective with actual students before they were persuaded to attempt it themselves in their own classroom. The teachers valued the practice teaching because they were given a chance to enact and revise their inquiry instruction in a low stress environment. For example, Heidi stated in the post-workshop interview that, "I don't think had we not practiced it the way we did teaching the Upward Bound students I don't think we would actually take it back and use it in our classrooms…I think it was really powerful how we took one small simple concept and kept the kids engaged for the full amount of time." Seeing the students engaged in learning through inquiry was important for many of the teachers. Karen stated that the practice teaching was meaningful to her because:

> I saw what difference it made in the participation of students; all students were able to participate whereas doing labs the old way some students will be in the background and probably let the other ones manipulate and answer the questions, but they were able to make their own observations; they were able to make their own inferences and they did not feel like they were being looked down upon if they gave an observation or they gave an inference that—because there was no right or wrong in the beginning inferences—and it freed them up to be able to really participate.

In addition to observing successful student engagement and learning, the teachers' reflection on their own and others' teaching through direct observation, discussion and video analysis solidified the components of the model that were vital to student learning. For example, Allison described how observing the other teachers' instruction pushed her to rethink her instructional timeline. She said that "it appeared as if they were trying to put in too much content into one 45 min lesson, mainly because if we were lecturing for that one 45 min lesson, we'd have been able to cover the entire concept, but when you break it down and having the students make their observations, their predictions and things like that and the questioning time, it stretches it out." Sam described the importance of coupling the practice teaching with group reflection in his post-workshop interview. He stated:

> If you think that you've learned something that can be helpful to you and helpful to your students then you can at least get a chance to get out there and stumble through a format that might … be a benefit to both of you, so you have a chance to fall down and get up and talk about, and it was really open. We were able to pat each other on the back and slam each other at the same time …but that being in a good sense, so it means everybody has a chance to question why you did it and what happened.

Through critiquing their own and their peers teaching they began to question the model and refine what they could use in their own classrooms with their diverse students. Jill described how "the moment we saw him [the CI] doing it, okay, we thought we all got it into our heads and we're going to try our own and then we started doing it and we realized that just imitating him wouldn't do." She found through the practice teaching that she needed time to learn how to ask critical thinking questions and experience with how much content she could teach through this new approach.

Not all the teachers were immediately comfortable with the reflection sessions. Jill described how she did not understand at first why the teachers were focusing on such small details in each lesson and felt that she "would be doing it right by practice, rather than sitting and reflecting and getting the positives and negatives out of it." However, through hearing the other teachers' feedback during the daily group reflections, she learned the value of this activity. She stated, "I think people are thinking for me when they reflect and I take their point and then I start reflecting. You know, when you look from your point of view it's a lot of points you don't see, but when you reflect from everybody's point of view and everybody reflects on [yours], and you have a group, then it stays with you." Others saw their reflective abilities improve over the institute. Mary stated, "I can see myself talking much more than in the beginning…now I can say exactly what was good, what was bad, how you can improve it, when did I see it, how I will approach it, what did I think that you should change and stuff like that." The importance of building a reflective and trusting community that involved both the teachers and the workshop facilitators was important to many of the participants.

Question #3: Were the Instructional Approaches Advocated in the Professional Development Model Reflected in the Teachers' Inquiry Instruction as Measured with the RTOP?

RTOP Classroom Observation Analysis

The RTOP was chosen as a measure of the teachers' ability to transfer the PD model to their classroom due to the close alignment between the program goals and the instrument items. Twelve lessons were analyzed during the school year following the summer institute, with the RTOP lesson scores ranging from 42 to 80, with a mean of 62 (see Table 3). 75% (9 of 12) lessons could be categorized as "reformed" as they had RTOP scores greater than 50 (MacIsaac and Falconer 2002).

Although high composite scores for lessons indicate an overall congruence with reformed pedagogy (Judson and Lawson 2007; MacIsaac and Falconer 2002; Roehrig and Garrow 2007), we chose to consider specific RTOP elements that would elucidate the particular aspects of the project that were (or were not) being incorporated into the teachers' practice. An area of relative strength was defined as one where the average of the group exceeded 3 for an RTOP item and an area of

Table 3 Teachers' RTOP lesson scores

Teacher	RTOP score
Heidi	42
Allison	44
Karen	48
Kevin	56
Kevin	58
Karen	61
Heidi	63
Sam	67
Allison	76
Jill	76
Jill	77
Mary	80
Average	62

weakness as one averaging less than 2. Of the 25 RTOP elements, 5 were categorized as "areas of strength" and three as "areas of weakness" ("Appendix 3").

RTOP Areas of Strength The teachers' overall strengths as shown through the RTOP analysis were their use of phenomenon first, their use of models, their engagement of students in various instructional approaches, their overall content knowledge, and their connection of lessons to fundamental ideas of their discipline. One RTOP element that the project leadership team emphasized consistently throughout the summer institute, was the "phenomenon first" approach to lesson design, where student exploration occurs prior to formal instruction on the topic. The average rating on this item for all of the lessons was a 3.08, which indicates a valuing of student ideas and negotiation of those ideas by the teacher before he/she chose to formally introduce the scientific conception. This result is important since it points to a shift in the teachers' approach to teaching scientific ideas (based on their pre-workshop interview responses) in the lessons we observed. The decision to withhold the "right answer" from the students until *after* the students were given the opportunity to experience, think about and discuss scientific phenomena is a difficult one for many chemistry teachers to make (Lyons et al. 1997); yet as a group, these teachers made that choice in the observed lessons. The lessons also were fairly reflective of an emphasis on using models or other "elements of abstraction" to explain scientific principles (average = 3.33) as well as a valuing of students' diverse ways of approaching the problem/situation at hand (average = 3.17). For example, in Allison's second lesson, her students were given the freedom to write their own procedure for carrying out the lab activity, rather than following a prescribed set of directions. Both of these outcomes support the notion that the teachers are valuing their students' thinking and honoring their attempts at trying to understand the world in their unique ways, depending on their prior knowledge and experiences.

A final area of relative strength, consistent with our observations of the teachers during the summer institute, was the lessons' focus on fundamental ideas of the science discipline (average = 3.92) coupled with the teachers' strong knowledge of the presented lessons' content (average = 3.33). It is fairly clear, through observations of them as a group, that these teachers were very comfortable with the ideas they were trying to communicate to their students. And although mastery of the domain of content knowledge is certainly not *sufficient* to teach science through inquiry, we would argue that is a *necessary* condition that must be present in effective reform-based classrooms. In fact, we would contend that it is not until a teacher develops a fairly high level of discipline-specific content knowledge that he/she is even *capable* of considering teaching in student-centered classrooms, since the pedagogical content knowledge (Shulman 1987) required to be effective in such an environment necessarily demands high levels of content knowledge.

RTOP Areas of Weakness RTOP Areas of Weakness. Three areas of weakness in the RTOP scores warrant discussion since they may speak directly to the PD model's effectiveness in equipping the teachers to carry out inquiry-based instruction effectively. The first two can be addressed together, since they are both connected to the lesson design domain of the RTOP score. Considered as a group, the lessons we observed had a low amount of student input in the direction of the lesson and did not encourage alternative modes of investigation to solve problems (1.92 and 1.83 average for all lessons, respectively). We would argue that this might be an artifact of the PD model that was promoted throughout the summer institute (guided inquiry through Predict–Observe–Explain, POE learning cycles) rather than a failure of the teacher to effectively implement the PD content. The guided inquiry lesson structure appeared to be a more accessible type of reform pedagogy for most of the classes we observed, so it is not surprising to see lower RTOP scores with regards to this aspect of lesson design. The second area of deficiency in the RTOP scores that relates directly to the PD efforts in the summer institute was the fairly low level of connection of the content to the real world or other disciplines during the observed lessons (average = 1.75). Although, the CI during the PD was careful to connect each lesson or experience enacted to common/real world experiences, these connections were only implicitly modeled in the instruction, and not explicitly taught as a part of the reform. Since the idea of connecting learning to the real world or other disciplines was not perceived by the PD leadership team as an area of intentional focus, it was not emphasized as strongly as other aspects of reform. We conclude from this data that in future iterations of this project, more attention should be given to explicit instruction on this element if it is expected to become a part of the teachers' instructional practice.

Discussion and Conclusions

The described professional development model moved the high school chemistry teachers toward more reform views of inquiry instruction and helped them to embrace a guided model of inquiry practice. The program's emphasis on the content instructor's modeling of content-specific inquiry lessons coupled with the practice teaching with high school students and intensive teacher reflection led to the greatest changes in teachers' beliefs about instruction. Observing the high school students engaged and thinking about science content during the practice teaching sessions was identified as moving the workshop experience from theory to practice. The extra scaffolding provided by the practice teaching sessions and subsequent video reflection facilitated the decision to move beyond, "this is a good idea" to the "I will try this idea" perspective. These ideas are consistent with the findings of other researchers who study the conceptual change of teachers through professional development efforts. Coaching, model teaching, and team teaching are often described as key components for transfer of reform-based strategies into teachers' classrooms after a professional development program (Akerson and Hanuscin 2007; Fullan and Stiegelbauer 1991; Joyce and Showers 1988; Luft 2001; Marx et al. 1997).

The program described in this paper differs from others in that it provides practice teaching to scaffold the teachers' inquiry instruction during the summer PD before the teachers return to their own classrooms. The practice teaching and reflection on this teaching used during the PD seemed to play a critical role in changing teachers' beliefs about the effectiveness and feasibility of inquiry instruction and helped them to overcome perceived challenges of transferring the method into their own classrooms. Both academic knowledge and experiential knowledge were given priority during the daily reflection sessions, allowing the teachers to problematize and then reduce the gap between the proposed theory and the inquiry practice (Garcia 2004; Loughran 2002). The scaffolded enactments (practice teaching followed by group reflection) during the summer helped the teachers to further “incorporate their innovations…in a real and lasting manner into their personal model of teaching” (Garcia 2004, p. 1243). The collaborative reflection time immediately after practice teaching gave the chemistry teachers concrete inquiry experiences to analyze. The teachers were encouraged through discussions and videotape analysis to view certain situations as problematic (e.g., teacher telling students concepts prior to providing an inquiry experience) rather than rationalizing the situation as a student problem or something outside their own control (Loughran 2002). The reflection time was important in that it gave the teachers time to wrestle with many of the common learning to teach tensions (telling vs. growth, confidence vs. uncertainty, safety vs. challenge) as a collective group before returning to their separate and often isolated school contexts (Berry 2007; Loughran and Berry 2005).

Another important component leading to change in beliefs among the chemistry teachers was their questioning of their content knowledge only after experiencing the chemistry inquiry lessons as students. This uneasiness or “cognitive dissonance” (Thompson and Zeuli 1999) followed by a building up of their content understanding through the sharing of predictions and explanations gave the teachers further confidence in the effectiveness of inquiry to increase their chemistry knowledge. The practice teaching then helped them to realize that the same method would successfully help high school students learn chemistry. Further, when the teachers recognized the considerable gaps and misconceptions present in their own understanding of fundamental ideas in chemistry, it was easier to be critical of their previous transmission- teaching model. Content knowledge instruction along with application of that knowledge (in our case through lesson development and practice teaching) has been connected with positive changes in teacher practice (Basista and Mathews 2002; Garet et al. 2001; Jeanpierre et al. 2005; Loucks-Horsley et al. 2003). Teachers need to learn through science experiences just as their students would and then take that learning to a higher level through application, revision, and refinement.

Studies conducted by other researchers have indicated that chemistry teachers (Roehrig and Kruse 2005; Roehrig et al. 2007) and other science teachers (Lotter et al. 2007; Luft 2001; Wallace and Kang 2004) who hold beliefs consistent with a constructivist framework more readily incorporate inquiry teaching practices into their classrooms after a professional development experience. Almost all the chemistry teachers in this study held beliefs compatible with the programs’ constructivist foundations prior to their participation in the PD project. However, the teachers’ misunderstanding of inquiry-based teaching and their inability to see how inquiry could be used to cover their content standards initially inhibited them from using the student-centered practices that they believed would result in student learning. After the workshop, the teachers viewed inquiry instruction as more manageable and applicable to their standards-based classrooms. The use of the POE model (Gunstone and White 1981; White and Gunstone 1992) was found to be effective in providing the teachers with a useful model that was easily transferred to their classrooms. The chemistry teachers believed that the model allowed them to increase their students' engagement and thinking, while at the same time allowing them to safely conduct laboratories and efficiently teach the content standards. Observing their students both motivated and engaged in the content through their inquiry lessons helped to sustain their inquiry practices into the academic year. Wallace and Kang suggest "that a view of inquiry as application and problem solving after concept introduction may be more viable in the secondary classroom than inquiry as induction of concepts" (p. 958). The teachers in our study found the POE guided inquiry approach applicable for concept introduction as well as an introduction to more student-centered inquiry investigations.

All of the chemistry teachers implemented the ideas from the PD model into their classroom during the academic year. The chemistry teachers' RTOP scores revealed reformed lessons that encouraged student predictions, hands-on exploration before explanations and conceptual understanding of the content standards. Although the teachers followed the guided-inquiry format presented in the workshop (lowering their numbers of 3's and 4's), their implemented lessons showed that they valued their students' voice in giving scientific explanations and directing their own learning in small groups. The teachers with the highest RTOP scores designed lessons in which their students participated more in the inquiry processes (helping to frame research questions, designing and critiquing procedures, etc.). Those with lower overall scores tended to retain more teacher-centered practices in their lessons (e.g., not facilitating "community building" and alternative modes of investigation/analysis). In their study of high school chemistry teachers' implementation of reform curriculum, Roehrig et al. (2007) found that the teachers who held more student-centered beliefs averaged higher RTOP scores with their observed lessons. School-based support from administrators during the implementation was also reported as an important factor for the teachers' successful inquiry teaching. Although our participating teachers met monthly with each other and program staff, more intensive in-school support may be necessary to move all of the teachers toward more sustained student-centered inquiry practices.

Implications for Professional Development

This study demonstrates the importance of providing an opportunity for teachers to change their practice along with their beliefs (Guskey 1986). The success of this PD effort in effecting significant changes in the ways teachers perceived their role in the classroom was influenced by the positive experiences in the "student" role as they worked through the content lessons in the summer institute. During this time, the teachers realized that learning through an inquiry approach engaged them in reconstructing their own chemistry content knowledge. Given time to reflect upon their experiences daily as individuals and as a group helped them to codify the features of the inquiry process that were most powerful in driving their own conceptual change and helped them consider the ways in which they could incorporate those same features in their own instructional context. Another essential element of the PD was giving the teachers opportunities to develop their inquiry teaching skills with adolescent learners prior to the end of the summer institute. During this phase of the PD, the teachers began to function as a professional learning community, where cycles of co-planning, instruction, reflective group critique, and lesson revision were effective in increasing the teachers' sense of self-efficacy towards using inquiry teaching approaches in their own classroom. The question that remains to be answered is the extent to which the teachers in this study continue to incorporate reform elements into their own teaching after the formal PD support has ended. Is there a "honeymoon" period during which the enthusiasm and novelty of the approach, coupled with the pleasant memories of the PD institute are sufficient to overcome the real and perceived barriers to inquiry instruction? That is, after some time, do the teachers return to their teacher-centered ways, or conversely, continue to increase the scope and magnitude of their reform practices? Further, do they become proficient enough with the model to serve as professional developers of their school and district colleagues so that the PD effort is extended beyond the initial cohort? Studies of this kind are needed to validate the claim that the changes that were observed would be robust to the diverse challenges that teachers encounter when moving beyond traditional approaches.

Appendix 1

Outline of Morning Pedagogy Session Activities

Day 1: What is Science?
Introductions
Think-ink-pair share: What is science and what is the essential knowledge base or nature of science?
NOS Card Sort Activity (McComas 1998)
Essential Features of NOS Discussion and activities

Day 2: What is inquiry?
Teachers brainstorm "what is inquiry" in groups and then share as a whole group on a transparency or large paper
Predict, Observe, and Explain Model (POE): M&M Diffusion Activity

Day 3: What is inquiry? Engaging learners in a scientific question
Catalase (potato vs. KI) enzyme activity with balloons
How does the amount or type of an enzyme influence the reaction?

Day 4: Formulate explanations from evidence (claim, evidence, reasoning) and connect to scientific knowledge/(Making Meaning)
Forensic Crime Activity: "Cafeteria Caper" from CourtTV http://www.courttv.com/forensics_curriculum/

Day 5: How can we model our thinking for our students?
Technology and Content integration-concrete to abstract

Tie M&M temperature activity to molecular simulations from Concord http://www.concord.org/

Day 6: Context and Science Processes
Discussion of Models of science (not one scientific method): Teacher groups delineate and describe processes used to solve scientific problems and compare to myth of one scientific method
Computer Simulations from PhET http://www.phet.colorado.edu/web-pages/index.html

Day 7: How do students learn? Inquiry and Formative Assessment
Discussion of Classroom Assessment Techniques (Angelo and Cross 1993) and whether teachers' instructional style matches how students learn.
Egg inquiry activity-POE pressure lab with liquid nitrogen

Day 8: Collaboration
Jigsaw method activity—Is there life on mars?
Home group discusses question "Is there life on mars?" Teachers separate into expert groups that each read a different pro/con article on the topic. Teachers then return to home group to discuss their articles and come up with a consensus answer to the question.

Day 9: WISE Lesson/Technology focus
In content pairs, teachers look at individual lessons on WISE website http://www.wise.berkeley.edu/

Day 10: Wrap Up!
Teachers convert cookbook laboratory into an inquiry laboratory in small content groups

Appendix 2

Pre-Institute Interview Protocol

1. Please describe your science background:
   a. Previous work experience
   b. Previous laboratory experiences
   c. Previous research experiences (In and out of college)
   d. How is science a part of your daily life?
2. How do you think people learn science? [How do you know when someone has learned something?]
3. What do you think are your greatest strengths and weaknesses as an instructor?
4. Describe an effective teaching lesson in your classroom and why you think it is effective.

5. How would you define inquiry science teaching?
6. Do you teach using the inquiry method?
   If yes, describe in your own words what a typical inquiry lesson looks like in your classroom. Include the following parts in your description:
   a. What are you doing? [What is your role as the teacher?]
   b. What are your students doing?
   c. How are books and resources used?
   d. How is science content taught?If no, is there a particular reason why you do not use this method? Describe what it would look like in your classroom if you were to teach using that method.
7. Do you think that inquiry teaching is a good way to teach science content? Why or why not.
8. Are there times or situations where inquiry teaching is not a useful method? Tell me about these.
9. What constraints do you feel you have to using inquiry teaching?
   a. How do you define (or understand) reflection?
   b. How and when have you reflected on your teaching during the school year?
   c. Describe a specific instance where you have reflected during the school year.
10. What do you hope to get out of this institute?
    a. What are you apprehensive about?

Post-Institute Interview Protocol

1. Describe some meaningful experiences that occurred during the content sessions in the first week of the institute. Why were these experiences meaningful to you? 2nd week?
2. Describe some meaningful experiences that occurred during the content-specific pedagogy sessions in the first week of the institute. Why were these experiences meaningful to you? 2nd week?
3. What did you learn from the large group pedagogy sessions during the institute?
4. Describe some meaningful experiences that occurred during the practice teaching sessions in the second week. Why were these experiences meaningful to you?
5. Have any of your ideas about best practices changed? Any ideas not changed?
6. How do you define (or understand) reflection?
7. What was the impact of the daily reflections on your views about teaching and learning?
8. How do you anticipate the workshop will influence your teaching during the academic year?
9. How do you define (or understand) inquiry?
10. Can you describe how you will teach inquiry in your classroom next year? (Describe a lesson example or how you will facilitate inquiry)

11. What is your view of the nature of science and how has it changed, if at all, during the workshop?
12. What would you suggest be done differently next year to improve the institute?
13. What would you like addressed during the academic year workshops?

End of Year Interview Protocol

1. What do you think you gained from your experience this year with the summer workshop and academic year workshops?
2. What, if anything, did you change about your teaching after going through the program? Why did you make or not make these changes?
3. Please briefly describe the lesson(s) that were videotaped in your classroom and describe your experiences with teaching these lessons. (If none videotaped—ask person to share any new inquiry lessons they taught this year and why they were not taped)
4. Describe one or two specific strategies that you *used* in your classroom this year that you learned from the professional development.
5. How do students learn science?
6. Describe an effective science lesson you taught and why it was effective? Has your view of what makes a lesson effective changed over the last year? Why or why not?
7. What guides your selection of instructional approaches?
8. How do your students influence your instructional choices, use of inquiry?
9. How does your instruction support development of thinking skills?
10. How does your instruction support development of social and collaborative skills?
11. How does your instruction support development of content understanding?
12. How do you define inquiry science teaching?
13. Do you teach using the inquiry method?

    If yes, describe in your own words what a typical inquiry lesson looks like in your classroom. What makes this lesson inquiry?
    If no, is there a particular reason why you do not use this method? Describe what it would look like in your classroom if you were to teach using that method.

14. What constraints do you still have to using inquiry teaching methods?
15. What did you find most beneficial from the academic year workshops?
16. What support or help do you still feel you need to be the best possible teacher?
17. How do you define (or understand) reflection?

    a. Describe a specific instance of your reflection during this school year.

Appendix 3

See Table 4.

Table 4 Teachers' individual RTOP lesson scores with subscale totals and averages

Name of teacher	Heidi	Allison	Karen	Kevin	Kevin	Karen	Heidi	Sam	Allison	Jill	Jill	Mary	Average
Respect prior knowledge	0	1	2	3	3	1	3	3	3	3	3	3	2.33
Learning community	2	1	2	3	3	2	2	3	3	3	3	3	2.50
Exploration first	2	2	3	3	2	2	3	4	4	4	4	4	3.08
Alternative modes	0	0	0	2	2	4	3	3	3	0	1	4	1.83
Directed by students	1	1	1	1	1	3	2	2	3	2	3	3	1.92
Total lesson design and implementation	5	5	8	12	11	12	13	15	16	12	14	17	11.67
Fundamental concepts	4	4	4	4	4	3	4	4	4	4	4	4	3.92
Conceptual understanding	3	3	2	3	2	2	3	3	3	4	3	2	2.75
Teacher understands content	3	4	3	3	3	3	3	3	4	4	4	3	3.33
Elements of abstraction encouraged	3	2	2	4	4	3	4	3	2	4	4	3	3.17
Connected to real world/disciplines	0	1	0	0	1	3	2	1	3	4	4	2	1.75
Total propositional knowledge	13	14	11	14	14	14	16	14	16	20	19	14	14.92
Variety to represent phenomena	2	2	3	3	3	2	3	3	4	4	4	3	3.00
Students predict/estimate/hypothesize	2	2	2	2	2	3	2	2	2	2	2	4	2.25
Students critically assess/thought	1	1	2	3	2	2	3	3	3	3	3	3	2.42
Students reflective about learning	1	2	2	2	3	1	3	3	3	3	4	3	2.50
Challenging of ideas	2	2	2	1	1	2	2	3	4	4	4	3	2.50
Total procedural knowledge	8	9	11	11	11	10	13	14	16	16	17	16	12.67
Variety of communication techniques	2	2	2	2	2	2	2	2	2	2	2	2	2.00
Divergent questions	2	2	2	2	2	2	2	2	2	3	3	2	2.17
High student–student talk	1	1	2	2	2	2	1	3	2	2	2	4	2.00
Student questions direct class	1	2	2	2	2	2	2	2	2	2	3	3	2.08
Climate of respect	2	1	2	2	2	4	2	3	3	3	3	4	2.58
Total classroom culture	8	8	10	10	10	12	9	12	11	12	13	15	10.83

Table 4 continued

Name of teacher	Heidi	Allison	Karen	Kevin	Kevin	Karen	Heidi	Sam	Allison	Jill	Jill	Mary	Average
Active participation of students	2	2	2	2	2	2	3	3	4	3	3	4	2.67
Alternative solutions, interpretations	1	1	1	2	2	3	2	2	4	4	3	3	2.33
Teacher patient	2	2	2	2	2	2	3	3	3	4	4	4	2.75
Teacher as resource	1	1	1	1	4	4	1	2	3	2	2	4	2.17
Teacher as listener	2	2	2	2	2	2	3	3	3	3	2	3	2.42
Total student/teacher relationships	8	8	8	9	12	13	12	13	17	16	14	18	12.33
RTOP total	42	44	48	56	58	61	63	67	76	76	77	80	62.33

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